

QC
849
D62

THE MARINER'S COMPASS IN AN IRON SHIP



J. WHITLY-DIXON

2/6

Cornell University Library

BOUGHT WITH THE INCOME
FROM THE

SAGE ENDOWMENT FUND

THE GIFT OF

Henry W. Sage

1891

A 126551

ENGINEERING LIBRARY

78/6/899

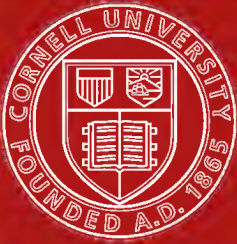
Cornell University Library
QC 849.D62

The mariner's compass in an iron ship; h



3 1924 004 599 365

engr



Cornell University Library

The original of this book is in
the Cornell University Library.

There are no known copyright restrictions in
the United States on the use of the text.

THE MARINER'S COMPASS IN AN IRON SHIP.

HOW TO KEEP IT EFFICIENT, AND USE IT
INTELLIGENTLY.

WITH

SOME REMARKS ON ELECTRIC INSTALLATION IN ITS
RELATION TO THE COMPASS.

BY

J. WHITLY DIXON,
Retired Captain, R.N.

WITH DIAGRAMS AND MAGNETIC CHARTS.

PORTSMOUTH:

GRIFFIN & CO., 2, THE HARD,

Publishers by Appointment to Her Majesty.

LONDON AGENTS: SIMPKIN, MARSHALL & CO.

1898.

[All rights reserved.]

PRICE TWO SHILLINGS AND SIXPENCE.

LONDON :
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.

PREFACE.

THIS little work has been undertaken at the suggestion of some of my brother officers now engaged in navigating her Majesty's ships. Its aim is to give a general statement of the facts and laws governing magnets and the earth's magnetism; to enable a seaman or reader to intelligently comprehend a mariner's compass, and the reason and order of its adjustment when disturbed by the iron of, or in, a ship.

Many admirable books and pamphlets on magnetism and the deviation of the compass exist, but the difficulty and inconvenience of consulting them all are obvious. The writer has endeavoured to compress in a small book all the necessary information likely to be required by an officer navigating one of her Majesty's ships or one of the mercantile marine.

The remarks relating to the disturbance caused by electric installation will, I believe, supply "a long felt want" to navigating officers.

In conclusion I can only thank my friends for their disinterested assistance in the shape of suggestions and criticisms.

J. WHITLY DIXON.

5, UPPER MONTAGU STREET,
PORTMAN SQUARE, W.
August, 1898.

LIST OF AUTHORITIES CONSULTED IN THE
PREPARATION OF THIS WORK.

Admiralty Manual of Scientific Enquiry.
Admiralty Publications on the Deviation of the Compass.
Bedford's Sailors' Pocket-Book.
Clerk-Maxwell's Electricity and Magnetism.
Collet's Compensation of Compass (translated by W. Bottomley).
Deschanel's Natural Philosophy.
Elementary Manual for the Deviation of the Compass.
Encyclopædia Britannica.
Encyclopædia Metropolitana.
Ganot's Physics.
Jenkin's Electricity and Magnetism.
Kelvin's—Thomson's Instructions for the Adjustment of Patent Compass.
Lardner's Electricity.
Lecky's Wrinkles.
Liverpool Compass Committee, Reports by.
Martin. Lectures delivered at the Royal Naval College.
Merrifield's Magnetism and Deviation of the Compass.
Raper's Navigation.
Reinold and Waghorn. Deviation of the Compass.
Royal Society, Philosophical Transactions of.
Royal United Service Institution, Journals of.
Towson's Practical Information on the Deviation of the Compass.
Walker's Terrestrial and Cosmical Magnetism.

ALGEBRAIC RULES.

The following simple algebraical rules and trigonometrical ratios should be known and attended to by the reader :—

Addition.

+ quantities added together give a + result.

- " " " " - "

To add together (+ and -) quantities, take the difference of their sums, prefixing the sign of the greater.

Subtraction.

Change the sign of the lower line and proceed as in addition.

Multiplication.

Like signs (+ +) (- -) give +. Unlike signs (+ -) (- +) give - sign.

Division.

If the Divisor and Dividend have like signs, the sign of the quotient will be +, and if the signs be unlike, the sign of the quotient will be -.

To obtain the logarithm of an angle—

Between 90° and 180° subtract angle from 180°.

Between 180° and 270° subtract 180° from the angle.

Between 270° and 360° subtract angle from 360°.

Below are the changes of sign in the trigonometrical ratios as an angle increases from 0° to 360°.

	Sin.	Cos.	Tan.	Cot.	Sec.	Cosec.
1st Quadrant 0° to 90°.	+	+	+	+	+	+
2nd Quadrant 90° to 180°.	+	-	-	-	-	+
3rd Quadrant 180° to 270°.	-	-	+	+	-	-
4th Quadrant 270° to 360°.	-	+	-	-	+	-

CONTENTS.

CHAPTER I.

	PAGE
MAGNETS—poles, magnetic field, magnetic fluid, magnetic substances, saturation point—SOFT AND HARD IRON	1

CHAPTER II.

TERRESTRIAL MAGNETISM—Variation, Dip and Intensity; their Diurnal, Annual and secular changes	9
--	---

CHAPTER III.

ERRATA.

- Page 1 line 8 for "for" read "form."
,, 7 ,, 19 for "clink" read "click."
,, 32 ,, 3 for "is" read "be."
,, 33 ,, 13 for "athwart" read "athwartship."
,, 42 ,, 15 for "connected" read "corrected."
,, 43 ,, 16 for "connected" read "corrected."
,, 64 ,, 12 for "principles" read "principle,"
,, 67 (line 3 from bottom) for "pen" read "pin."

CO-EFFICIENTS—A, B, C, D, AND E—their meaning and values ascertained— λ (lambda) value of	
HEELING ERROR—Causes of— μ (mu) value of—correction of Heeling error by Vibrations and Heeling error instrument—HEELING CO-EFFICIENT	46

CHAPTER VI.

COMPASS—Mechanical correction of—General remarks and cautions	60
---	----

Tables and MAGNETIC CHARTS.

ALGEBRAIC RULES.

The following simple algebraical rules and trigonometrical ratios should be known and attended to by the reader :—

Addition.

+ quantities added together give a + result.

— " " " " — "

To add together (+ and —) quantities, take the difference of their sums, prefixing the sign of the greater.

Subtraction.

Change the sign of the lower line and proceed as in addition.

v

Below are the changes of sign in the trigonometrical ratios as an angle increases from 0° to 360° .

	Sin.	Cos.	Tan.	Cot.	Sec.	Cosec.
1st Quadrant 0° to 90° .	+	+	+	+	+	+
2nd Quadrant 90° to 180° .	+	—	—	—	—	+
3rd Quadrant 180° to 270° .	—	—	+	+	—	—
4th Quadrant 270° to 360° .	—	+	—	—	+	—

CONTENTS.



CHAPTER I.

	PAGE
MAGNETS—poles, magnetic field, magnetic fluid, magnetic substances, saturation point—SOFT AND HARD IRON	1

CHAPTER II.

TERRESTRIAL MAGNETISM—Variation, Dip and Intensity ; their Diurnal, Annual and secular changes	9
---	---

CHAPTER III.

COMPASSES—Lord KELVIN, Liquid, PEICHL, and Landing—BEARING PLATE—POSITION OF COMPASS, PEDESTAL FITTINGS—ELECTRICAL INSTALLATION	20
---	----

CHAPTER IV.

DEVIATION, by distant object, terrestrial or celestial, RECIPROCAL bearings, DEFLECTORS, CONTROL COMPASS—PERMANENT AND SUB-PERMANENT MAGNETISM	
GAUSSIN ERROR in ship or torpedo boats—SUB-MARINE disturbance .	
CAUSES OF SEMI-CIRCULAR, QUADRANTAL, HEELING and CONSTANT ERRORS—HEELING CO-EFFICIENT	30

CHAPTER V.

CO-EFFICIENTS—A, B, C, D, AND E—their meaning and values ascertained— λ (lambda) value of	
HEELING ERROR—Causes of— μ (mn) value of—correction of Heeling error by Vibrations and Heeling error instrument—HEELING CO-EFFICIENT	46

CHAPTER VI.

COMPASS—Mechanical correction of—General remarks and cautions .	60
---	----



Tables and MAGNETIC CHARTS.

THE MARINER'S COMPASS.



CHAPTER I.

MAGNETISM.—The following sentences from the works of three great philosophers may fitly preface any work, however small or simple, relating to magnetism. The late Sir John Herschel, writing on the magnetic condition of our globe, states: “The relations of terrestrial magnetism lie among those mysterious powers which seem to constitute the chief arcana of inanimate nature and its phenomena for a singular exception to the character of stability and permanence which prevails in every other department of the general subject.”

M. Arago writes: “Nothing in the vast domain of terrestrial physics is more obscure and more uncertain, than the causes which everywhere occasion the three elements of terrestrial magnetism, viz., the declination, inclination and intensity of the force to vary.”

The late Sir Edward Sabine also writes: “All attempts that have hitherto been made to connect the secular magnetic change with any other physical phenomena, either terrestrial or cosmical, have signally failed.”

MAGNETISM.—Certain substances, natural or artificial, have the power of attracting iron, and are popularly known as MAGNETS, the cause of this attraction is called magnetism.

The natural magnet or Lodestone ($\text{Fe}_3 \text{O}_4$) was formerly considered to possess magical qualities, and it was not until the tenth or twelfth century that its property of pointing

when suspended by a thread to the magnetic meridian was discovered.

The Lodestone, from the Saxon "læden," to lead, is found in the older geological formations in Sweden, Spain, Arkansas, the Isle of Elba and other portions of the world.

ARTIFICIAL MAGNETS. — Any bar of iron or steel, if rubbed by a lodestone or artificial magnet will be found to be magnetised, that is to say, if freely suspended it will take up a known position with regard to the astronomical or true north and south, and also with regard to the horizon.

If the magnetised bar be placed in iron filings, it is found that they are most strongly attached towards the ends, decreasing towards the centre, where a neutral position exists, and no filings will be attracted.

POLES. — The points near the end where the greatest attraction exists are called poles; the imaginary line joining them the axis of the magnet, and Dr. Gilbert, one of the earliest writers on magnetism, calls the *neutral* position the *equator* of the magnet.

POLES, POSITION OF. — The poles of a magnet, are not at its extremities, but generally a short distance from the end. The position of poles is generally about $\frac{1}{12}$ th of the whole length of the bar from its ends; the thinner a bar or needle the nearer the poles approach the extremities.

The two poles in the previous experiment with the iron filings would appear to be identical, but this is not so, for when a similar pole of a magnetic needle or bar is brought to that of a freely suspended magnetic needle, repulsion takes place; if the opposite pole is brought near the needle, attraction takes place, hence the following rule.

Poles of the same name repel and poles of a contrary name attract one another, with the undermentioned exception. If the red pole of a strong magnet be held at some distance from the red end of a weak magnet, it will repel the latter, but if brought closer, it will attract it. This apparent paradox is owing to the magnetism induced

by the stronger magnet in the weaker, is opposite to the original magnetism of the latter and the induced magnetism finally overcomes the original magnetism of the weaker magnet.

EARTH AS A MAGNET.—Dr. Gilbert, towards the end of the sixteenth century, discovered the inherent magnetism of the earth, speaking generally, there are two poles of opposite character with a magnetic equator midway between them.*

NAMES OF POLES.—Bearing in mind the law previously mentioned that poles of the same name repel, and poles of a contrary name attract one another, it is evident that the magnetism of the north polar regions is opposite in name to that existing in the pole of a compass needle which points to the north; hence the confusion in nomenclature between various writers; to avoid all ambiguity, we shall call the poles of a magnet that attracts the north-seeking end of the needle blue, the repelling one red, bearing in mind the pole in the north end of a compass needle is a true south pole, and that in the south end of a compass needle is a true north pole.

When speaking of the Mariner's compass the custom of seamen will be followed, calling the points according to the graduation of the compass.†

The late Sir G. B. Airy, in diagrams, marks the magnets



Red magnetism

Blue magnetism



Makers usually mark ‡ the red pole of a magnet by a transversal cut.

* See further remarks, under the heading of Dip and Intensity, pages 16-19.

† It is to be regretted that all Mariner's compasses are not graduated from 0° to 360° .

‡ For marking of service magnets, see page 66.

POLE, STRENGTH OF. *—Is defined as proportional to the force which it is capable of exerting on another given pole; hence the force (f) exerted between two poles of the strengths (m) and (m_1) must be proportional to the product $m m_1$. The force (f) is also found to be inversely proportional to the square of the distance (D) separating the poles, and to depend on no other quantity; hence choosing the units correctly,

$$f = \frac{m m_1}{D^2} \quad (1)$$

The strength of a pole is a magnitude which must be measured in terms of some unit. When in the above equation we make (f) and (D) both equal to unity, the product $m m_1$ must also be equal to unity, hence from equation (1) it follows that “the unit pole is that which at the unit distance repels another similar and equal pole with unit force.”

The law may be briefly stated thus—the force exerted between two magnetic poles is proportional to the product of their strengths, and is inversely proportional to the square of the distance between them: This law of inverse squares is only true when the distance between the poles is sufficiently great that the magnetism due to mutual induction may be safely neglected.

The effect of a small magnet on a distant magnetic mass depending on the attraction of one pole and the repulsion of the other will be inversely as the cube of the distance nearly.

The attraction between two magnetisms (the permanent magnetism of the magnet, and the induced magnetism of the iron), which is as the product of these magnetisms directly, and as the square of the distance inversely; will

* MAGNETIC UNIT.—A Unit Magnetic Pole is one of such a strength that, when placed at a distance of one centimetre from a similar pole of equal strength, it repels it with a force of one dyne.

be inversely as the fourth power of the distance. With increase of distance, therefore, the attraction diminishes very rapidly.

POSITION OF POLES WHEN MAGNET IS BROKEN.—If a magnet be broken into several pieces, each portion becomes a complete magnet, with a red and blue pole, and each piece is almost as strongly magnetised as the original magnet, if the pieces be again brought closely together, the pieces revert to a single magnet, with a red and blue pole.

MAGNETIC FIELD.—The neighbourhood of the magnet is often for convenience called a magnetic field, and the effect produced by a magnet is often spoken of as due to the magnetic field. The lines of force in a uniform magnetic field will be parallel. The distance between the poles of a magnet, multiplied by the force of either pole, is called the MOMENT OF THE MAGNET. The intensity of magnetisation of a magnet is the ratio of its magnetic moment to its volume.

MAGNETIC FLUID.—In order to explain the various phenomena of magnetism, two hypothetical magnetic fluids are assumed (the fluids are not liquids) and represent an invisible, elastic, gaseous atmosphere surrounding the particles of all magnetic substances; the fluid facing the north has red magnetism, and the one to the south blue.*

Before magnetisation, it is assumed, these fluids are combined round each molecule and mutually neutralise each other; they can be separated by the influence of a force greater than that of their mutual attraction, and can arrange themselves round the molecules, to which they are attached, but cannot be removed from them.

The above hypothesis appears to be convenient, more especially with regard to that magnetic phenomena which

* The French writers call the fluid facing the north Boreal, and the other Austral.

appear to result from electrical currents, circulating in magnetic bodies, connecting the theory of magnetism with that of electricity.

COERCIVE FORCE.—*Soft-iron** is either malleable iron which has not been hammered or subjected to any violence when cold; or cast iron. It is instantly magnetised by induction when exposed to any magnetic force, but has no power of retaining magnetism.† *Hard iron*,* on the contrary, when once magnetised retains its magnetism, when the inducing force is removed—hard iron or steel may be magnetised by percussion, if held vertically, or still better in the line of dip. A hard iron bar or steel may be artificially converted into a magnet by means of a single powerful magnet drawn from fifteen to twenty times in the same direction along the bar or needle; the end last touched being of opposite polarity to the pole of the magnet used; this method should only be employed for small magnets or needles. The usual process is to apply to the centre of a steel bar when laid on wood, the opposite poles of two magnets held obliquely at an angle of about 30° to the steel bar, drawing the magnets about ten times slowly along to the opposite ends of the bar, then turn the bar over and treat it in a similar manner on the other face; it will then be found that the steel bar has become permanently magnetised.

A third method of producing most powerful magnets is by rods or bundles of wrought iron round which an electric current circulates in a coil of wire—in a steel magnet the permanency depends on the quality of the steel; for

* The reader should clearly understand that the iron used in the construction of a ship there are many descriptions that cannot be classed as either hard or soft iron. No iron is perfectly soft, and no steel perfectly hard. Theoretically the magnetism in a magnet is not quite fixed, for no steel is so hard as not to be temporarily affected by magnetic induction.

† A piece of soft iron, which is a magnet by induction, can induce magnetism in another piece of soft iron; thus a magnet may sustain a long string of nails, each hanging to the one above it.

compass needles the steel should be perfectly uniform in hardness but of spring temper.

SURFACE MAGNETISATION.—In many cases the magnetism imparted to magnets is confined chiefly to the outer layers of steel, if the outer layers are dissolved by acid, it loses its magnetism after a thin film has been removed. Magnets, which have been thoroughly magnetised, however, exhibit some magnetism in the interior. A hollow steel tube when magnetised is nearly as strong a magnet as a solid rod of the same size: if a bundle of bound steel plates are magnetised, the inner ones may occasionally exhibit a reversed magnetisation. Heat diminishes the power of a magnet, if a steel one is raised to a white heat it is permanently demagnetised.

MECHANICAL EFFECTS OF MAGNETISATION.—Joule found an iron bar to increase by $\frac{1}{720000}$ of its length when powerfully magnetised, but as its volume remained the same, it contracted in thickness—if magnetisation or demagnetisation is effected suddenly, a faint metallic clink is heard. A twisted iron wire tends to untwist itself when magnetised: a piece of iron when powerfully magnetised and demagnetised in rapid succession grows hot.

MAGNETIC SUBSTANCES.—Iron, nickel and cobalt are (magnetic) * paramagnetic, being attracted to either pole of the magnet, and if suspended between the poles of a magnet tends *axially*, that is, to place its length parallel to the lines of force.

Bismuth and antimony are diamagnetic bodies, being repelled by either pole of a magnet, and if suspended between the poles of a magnet, tend *equatorially*, that is, to place its length at right angles to the line of force.

SATURATION POINT.—When the highest degree of retainable magnetisation is reached in a steel bar, it is said to be magnetised to saturation; by means of powerful magnets, a

* Strictly, the word magnetic ought to be a general one, including all the phenomena and effects produced by that power.

steel bar, more especially if newly made, may be temporarily magnetised beyond saturation, but it rapidly returns to saturation point.

The Force in a magnetised needle is simply directive, but has no power to move the needle, is evidenced by the fact that a magnetised needle floating freely on cork in a liquid, does not move, the attracting force of the red pole is exactly equalled by the repelling force of the blue; in addition the weight of a needle is the same before and after magnetisation.

CHAPTER II.

TERRESTRIAL MAGNETISM. — A freely suspended magnetic needle takes up a certain position with regard to the *true or geographical north*, and also with regard to the horizon, the phenomena relating thereto are called terrestrial magnetism ; the three elements required in order to denote the magnetism of any place on the earth's surface are the Variation (declination), Dip (inclination), and the Intensity of the Magnetic Force. The two former are constantly brought under the notice of a seaman during a voyage, and the third, Intensity, is the force which tends to set itself in the direction of the line of the dipping needle, that is in the lines of force, but for purposes of compass correction, it is better to consider this as being composed of two component parts—a horizontal force acting parallel to the earth's surface, and the other a vertical one, acting at right angles to the horizontal force, pulling the red end of the needle downwards in the northern magnetic hemisphere, and upwards in the southern one.

Lines of equal Variation, Dip, and Intensity, are called ISOGONIC, ISOCLINIC, and ISODYNAMIC lines respectively.

The term MAGNETIC EQUATOR is usually applied to the line of no dip, but it would be more correctly applied to the curve which cuts all the magnetic meridians at right angles. The DYNAMIC EQUATOR is the curve on the earth's surface connecting the points of least magnetic intensity. MAGNETIC POLES are positions of vertical dip (90°), but they do not coincide with those of the greatest vertical force ; also the positions of greatest intensity do not coincide with the

magnetic poles, the former are usually called magnetic foci or centres. The above magnetic elements are subject to regular and irregular changes, the former are called Secular, Diurnal, and Annual; and to the irregular changes, when taking place simultaneously over large surfaces of the earth, the term MAGNETIC storms have been applied.

Various hypotheses have been advanced to connect the above elements obtained by observation with a system, but although the general facts may be shown, there are distinct discrepancies between theory and observation, and it is probable that the earth's magnetism cannot be reduced to any mathematical expression. Halley, Mayer, Humboldt, Biot, Hansteen and Gauss, have all advanced theories on the subject.

The cause of the earth's magnetism remains as yet unexplained. The late Sir G. B. Airy considered that terrestrial magnetism was not produced to any large extent in the earth's surface, supporting the latter proposition by observations made on mountains and in balloons.* Gauss considered that the agents producing the magnetic force of the earth, or the greater portion of them, were situated exclusively in the interior of the earth; Gauss also considered that the cause of terrestrial magnetism was not external to the earth. The late Sir G. B. Airy states: "There is reason to believe that the sun and moon act as magnets," this has been conclusively proved in the 'Adams' Prize Essay for 1865,' by E. Walker, M.A.† Magnetic disturbances occur simultaneously at places thousands of miles apart, their periodical nature, length, times of maxima and minima, being coincident with those of solar spots; and that the magnetic force in

* This question is still further complicated by the fact that the amount of oxygen in any known volume of air will vary with its altitude, and oxygen is paramagnetic.

† Published by Deighton, Bell & Co., Cambridge. This excellent work, for clearness and conciseness, leaves nothing to be desired, and should be in the hands of every naval officer interested in magnetism. Chapter II. is largely based on it.

both hemispheres during the months of December, January and February, is greater when the sun is nearest the earth ; than in May, June and July, when it is more distant. The discovery of a semi-annual * and lunar-diurnal change in the diurnal variation, point to a cosmical origin, but whether the sun acts by direct heating power (which appears unlikely), or indirectly ; and the moon from induced magnetism received from the earth, is at present undetermined. It is probable that the agents producing terrestrial magnetism are both physical and cosmical, modified or complicated by earthquakes, volcanic eruptions, and sudden atmospheric changes,† and the secret of terrestrial magnetism is “ reserved for the industry of future ages.”

VARIATION (DECLINATION) is the horizontal angle between the true and magnetic meridians. The first European to note the variation of the compass needle was Columbus, on September 13th, 1492, in latitude 28° N., and longitude 28° W. ; doubtless the early navigators knew that the true and magnetic meridians did not coincide, but Columbus found that the Variation itself changed ; in China, the Variation was mentioned in the early part of the twelfth century. Boroughs, Comptroller to the Navy in Elizabeth's reign, published a work called ‘ A Discourse on the Variation of the Cumpas or Magneticall Needle ’ ; the variation at Limehouse (16th October, 1580) was $11^{\circ} 18'$ E. The secular change in the Variation was made known by Professor Gelli-

* See pages 13 and 14.

† Wind-storms do not appear to exercise any perceptible influence on the magnetic needle, but Gilpin states, from observations made in 1786–87 at Somerset House, that he found a change of wind produced a variation in the needle from steady to unsteady, or the contrary. The needle was most steady when the wind was south or south-west, and most unsteady when it was east.—Walker, page 63. With regard to thunderstorms, the late Sir F. Evans (apparently on the authority of the late Sir G. B. Airy) states that they exercised no perceptible influence on the needle. Macdonald in 1794, and the late Father Secchi held contrary opinions. With regard to lightning, in wood-built vessels the poles of the needles have been reversed ; in an iron-built ship, if struck with lightning, her magnetic character would probably undergo considerable change.

brand, of Gresham College, in a work called 'A Discourse Mathematicall on the Variation of the Magneticall Needle, together with its admirable diminution lately discovered'; from this date, the secular change in the Variation was recognised. The following tables showing the secular change in the Variation for London and Cape of Good Hope are given :—

LONDON.			CAPE OF GOOD HOPE.		
Easterly variation marked +			Annual eastward change +		
Westerly variation marked -			Annual westward change -		
Date.	Variation.	Mean Annual Westward change.	Date.	Variation.	Mean Annual Westward change.
1580. .	11°15+	..	1605. .	0°30+	..
1634. .	4°6+	10°6'-	1675. .	8°14-	7°06-
1672. .	2°30-	10°5'-	1751. .	19°15-	6°62-
1723. .	14°17-	8°1-	1792. .	24°31-	5°68-
1773. .	21°9-	9°3-	1839. .	29°09-	13°00- (in 1836)
1805. .	24°8-	0°7-	1842. .	29°06-	0°29+
1818. .	24°43-	Maximum	1849. .	29°16-	2°15-
1858. .	21°54-	6°8+	1895. .	29°24-	..
1898. .	16°59-	7°0+	1898. .	29°16-	2°5+

The *Diurnal change* in Variation was first noticed by Mr. Graham, an instrument maker of London, in 1722, finding that the diurnal variation being about 50' (from 14°·45' to 13°·50'). In a paper read before the Royal Society, by Canton, on December 13th, 1759, it was shown that the diurnal change was generally regular, *i.e.*, the variation of the needle westward increased from 8 or 9 A.M. until 1 or 2 P.M.; the needle remained stationary for some time, but proceeding to return to its approximate normal position during the night or by next morning. Canton found that the extent of the diurnal range was greater in

summer than in winter.* Macdonald, in Sumatra, in 1794, found that the easterly diurnal change of the variation increased during from 7 A.M. to 5 P.M., and decreased from that time until 7 A.M. the next day. From his observations,† Macdonald deduced two general rules—

- (1.) That the amount of the diurnal change is less in the tropics than in temperate climates.
- (2.) The motion of the needle in the southern hemisphere is in the opposite direction to that in which it moves in the northern hemisphere at the same hour.

The first rule is generally correct, but no definite relation exists between the latitude and the extent of the daily change. The second rule is not correct so far as tropical regions are concerned. The late General Sabine, from five years' observations made at Singapore, St. Helena, and the Cape of Good Hope, shows "that, for one half of the year, the diurnal motion of the needle corresponds to that observed in the northern hemisphere at the same hours, whilst for the other half it corresponds to the motion in the southern hemisphere." The passage from one direction of motion to the other takes place soon after the equinoxes, *i.e.*, *when the sun crosses the terrestrial equator*; at this period of the year, the diurnal variation partakes more or less on different days of the character of both seasons, but at all other periods the contrariety is unmistakable, "the north end of the needle reaching its eastern extreme in one case, and its western extreme in the other, at nearly the same hours, and it must be further noticed. that these extremes are, in both cases,

* Canton also noticed that irregular movements of the needle were accompanied by an Aurora Borealis, a fact also discovered by Wargenten in 1750.

† During these observations Macdonald inferred a diurnal change in the dip, noticing that the needle did not always remain at the same inclination to the horizontal plane.

equidistant from the mean position of the needle in the respective months."

Investigation of the above observations revealed the existence of a semi-annual change in the diurnal change, having opposite phases, according as the sun's declination is north and south.

LUNAR-DIURNAL CHANGE.—The influence of the moon on the three magnetic elements was first announced by M. Kreil in 1841, and confirmed by General Sabine in 1856, stated briefly, the variation has two easterly and two westerly maxima, and the dip and total force have likewise each two maxima and two minima in the same interval, the change in each case passing through zero four times during the lunar day.*

In Paris, the diurnal change of variation reaches its maximum eastward direction at $8\frac{1}{4}$ h. A.M., $8\frac{1}{8}$ P.M., and maximum westward direction at $1\frac{1}{4}$ P.M. and 11 P.M., agreeing closely with those at Kew. The diurnal change varies in different months, the greatest range taking place in April ($13'$), and the least in December ($6'$). The change in the position of the needle is effected not by a steady progression, but by a series of small oscillations.

ASTATIC NEEDLE.—If it be required to ascertain the maximum and minimum effect of the disturbing cause on the magnetic needle, and not the actual amount of the variation, the needle is made astatic by placing two needles of the same force parallel to each other, with their poles in a contrary direction, but with the two needles rigidly connected at their centres; the terrestrial magnetic direction is neutralised, the needle retaining all its natural power, and its sensitiveness is greatly increased.

* The lunar magnetic influence is less felt in winter, owing to the effect being so small, that it is probably swallowed up in the greater irregular disturbances that prevail with more frequency during the winter than in summer.

ANNUAL OR PERIODICAL change of the Variation.—In addition to the secular change, it was discovered by Cassini, in 1786, that the magnetic needle was subject to small annual periodical fluctuations. From the observations of Cassini and Gilpin, M. Arago suggested certain hypotheses with regard to the annual change, which subsequent experience has not confirmed; they are, therefore, not mentioned.* It is almost certain there does exist on the globe an annual change of the variation, irrespective of the direction or magnitude of the variation, its secular change, or the geographical position of the observer; and depending on the sun's position with reference to the equator, causing the *red* end of the needle to point more to the *east* when the sun is *north*, and to the *west* when it is *south* of the equator; the turning-points must, therefore, be approximately at the times of the equinoxes. The amount of the annual change is small, and varies, as stated above, at different times of the year.

IRREGULAR CHANGES in the Variation occur during earthquakes, volcanic eruptions, and the appearance of the Aurora; the effect of the latter on the magnetic needle extends considerably beyond its visibility. The *magnetic perturbations* or *magnetic storms* have been simultaneously observed at Toronto, Cape of Good Hope, Prague, and Hobart, and have been connected by the late General Sabine with the periods of maximum sun spots, *i.e.*, approximately every eleven years.

The variation of the compass in shore observatories is obtained by means of the declination compass,† if desirous of ascertaining the variation, by the compass supplied to Her Majesty's ships (landing one).‡ Obtain the true bearing of six well-defined objects, about 60° apart (to eliminate, as far as possible, errors of centring, graduation, etc.), from an observation spot free from iron; the mean

* Walker, pages 63, 70, 72, 76. † Ganot's 'Physics,' page 67.

‡ See page 23.

of the bearings of each object, by attracting and repelling the red end of the needle, should be used.

Different caps and pivots should be employed to prevent error in this respect ; the observations should be repeated at such hours that the variation will not be affected by the diurnal change ; the error of the observing card, if known, should be applied.

DIP OR INCLINATION* was first observed by Norman, an instrument maker in 1756 ; it is the angular difference measured in the vertical plane, between the direction of the needle and the horizontal plane or zero. If the *red* end of needle dips below the horizon, it is usually called north dip, with a + sign affixed ; when the *blue* end of the needle dips below the horizon it is called south dip, with a - sign affixed.† In a vessel proceeding from London with a dip of + 67° to the Cape of Good Hope with a - 58°, an observer would notice the needle gradually assuming a horizontal position ; on reaching the magnetic equator (ACLINIC LINE), the dip would be nil and the needle horizontal ; proceeding south, the blue end of the needle would gradually dip, until, on arrival at the Cape of Good Hope, it would make an angle of 58° with the horizontal plane.

The dip is subject to secular, diurnal, and annual changes in a similar manner to the variation. The secular change varies in different portions of the globe. The Bight of Benin is where one of the most rapid changes takes place ; at TAHITI, the change in sixty-seven years was 35' ; at the present time (1898), the annual change at the Cape of Good Hope and Kew is respectively 5' increasing, and 1'·7 decreasing.

The diurnal change of the dip has its regular horary variations, turning points, and its maxima and minima, they

* The relationship between dip, horizontal, vertical and total force will be shown under the heading of Intensity. See page 18.

† The method of obtaining the dip both on shore and at sea may be studied in the 'Admiralty Manual of Scientific Enquiry,' article 'Terrestrial Magnetism ;' Walker, page 155 ; and Ganot's 'Physics,' page 581.

are as well defined as those of the variation, but they vary at different geographical positions. At some observing stations a semi-annual period has been discovered in the hours of the principal maxima and minima, viz., from April to September, and from October to March ; but as the diurnal change in the dip is only a few minutes, it has no practical value to a seaman.

SEMI-ANNUAL CHANGE OF DIP.—From observations made at Toronto with a + dip, it appears that the inclination is less during the months when the sun is south of the equator, than when it is north of it, the mean result coinciding approximately to the time of the equinoxes ; a similar result is found from Hobart observations with a - dip, the amount being about 15'.

The following table shows the secular change in the dip for the neighbourhood of London * :—

Year.	Dip.	
	°	'
1580	71	50+
1672	73	30+
1723	74	42+
1773	72	19+
1821	70	03+
1860	68	19+
1898	67	20+

INTENSITY.—Having given a general description of terrestrial magnetism so far as it relates to direction, we now consider its *strength* or *intensity*. To Humboldt is given the credit to demonstrate its existence in 1798–1803. As previously mentioned, the total force acts in the line of dip ; it is generally resolved into its component parts, *horizontal force* and *vertical force*, and for the purpose of this work, horizontal force and vertical force, dip, and the variation are

* Walker, page 177.

considered. The connexion shown in the figure below is for Kew and the south coast of England generally.

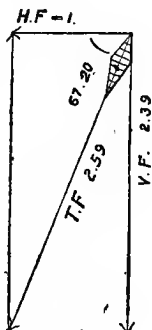


FIG. 3.

- H. F. is the horizontal force.
 V. F. „ vertical force.
 T. F. „ total force.
 D. ($67^{\circ} 20'$) is the dip (red end).
 $H. F. \times \sec D. = T. F.$
 $H. F. \times \tan D. = V. F.$
 $T. F. \times \cos D. = H. F.$
 $T. F. \times \sin D. = V. F.$
 $V. F. \times \operatorname{cosec} D. = T. F.$

The horizontal force is assumed to be unity for convenience, but the earth's total force, if expressed in British units, varies from 6.0 to 15.2 , the units being a second of time, a foot in length, and a grain in weight; in Continental countries they are a second of time, the millimetre (0.03937 of an inch, or 0.00328 of a foot) and the milligramme (0.01543 of a grain). To convert British into Continental measure, multiply by 0.46108 , and *vice versa*, multiply by 2.1688 .*

The C. G. S. system is usually adopted in modern textbooks, it has been recommended by the Royal Society; to obtain the earth force according to the C. G. S. system from British values, multiply the latter by 0.04611 , and divide the Continental by 10 .

From the above figure it will be seen that at the magnetic equator the horizontal and total forces are equal, the former decreasing and the latter increasing until one of the magnetic poles is reached, where the horizontal force is nil and the total force at a maximum; but the foci of greatest intensity are not coincident with the magnetic poles. As the total force cannot be directly measured, its horizontal component is determined by vibrations of a

* 'Admiralty Manual,' article 'Terrestrial Magnetism.'

magnetic needle in a given time, or by statical measurements.*

The Total force or Intensity is subject to secular, diurnal, and annual, or semi-annual changes in a similar manner to the Variation, the annual change being governed by the position of the sun in the equator, being greater in both hemispheres in December, January, and February, when the sun is nearer the earth, than in May, June, and July, when it is farther away. Gauss considered the total magnetic action of the earth is the same as that which would be exerted if in each cubic yard there were eight bar magnets each weighing a pound.

* 'Admiralty Manual,' article 'Terrestrial Magnetism.'

CHAPTER III.

THE previous chapters treating of the laws of magnetism generally, with reference to those governing the magnetic needle, are intended to enable the reader more clearly to understand the general laws before proceeding to describe the compass itself.

THE COMPASSES used in H.M. Navy are Sir William Thomson's (Lord Kelvin), an improved Liquid Compass, PEICHL, and the Landing Compass, formerly the Admiralty standard; on the principal steamship companies Sir William Thomson's is largely used.

THOMSON'S COMPASS.—In H.M. ships larger than the "Destroyer class," Sir William Thomson's compass is used as a standard, also principally in other steering positions, the exceptions being the conning tower and protected stations between decks.* Its method of suspension, although greatly superior to the old Admiralty system, still leaves room for improvement in modern fast cruisers, where the vibration is considerable when steaming at high rates of speed, and where it is placed on a superstructure (owing to the exigencies of the service) such as a chart room.

The card is very light, possessing small needles of sufficient directive power; the oscillation is slight, the greater portion of the weight of the card being near its edge, thus producing a long period of vibration. The outer graduation of the numerals in the standard compass card is inverted to enable the card to be read direct with the azimuth mirror.

* See page 22.

The compass bowl is fitted with a graduated verge for horizontal angles.

AZIMUTH MIRROR.—A description of its construction would be out of place in this small work ; it is placed on the upper surface of the glass in the bowl, turns freely in azimuth, and is capable of observing terrestrial, solar and stellar objects ; it is also fitted with a shadow pin for rough observations. Care should be exercised not to communicate the motion of the azimuth mirror to the bowl, and if the observed object be indistinct, it is advisable to reflect the card to the object.

THE LIQUID COMPASS,* used in destroyers and torpedo-boats, has been found to be fairly sensitive and steady, considering the class of vessel in which they are used. The cards are fitted with needles, of great directive power, placed edgewise, floating in a fluid composed of two portions of distilled water, and one of pure spirits of wine. The cap is a sapphire with a pivot point of metal (**IRIDIUM**), the pressure of the card on the latter should not exceed one hundred grains. A means of filling is provided should bubbles appear, and in addition the bowl is fitted with an elastic or expansion chamber, by which the fluid passes into or out of the bowl on change of temperature.

The air is exhausted (as far as practicable) from the fluid by an air-pump, the bowl is then closed and hermetically sealed ; should large bubbles appear it would point to a serious defect, and it is desirable in such cases to return the compasses to a dockyard or the makers. The liquid compass when used as a standard, in addition to a shadow pin, is fitted with a removable azimuth circle, carrying a sight vane and a reading prism, and it is well adapted for all observations during daylight;† the numerals marking the graduation might be slightly increased in size with advantage.

* By E. Dent & Co., 61, Strand, London.

† A system capable of taking observations at night, under the conditions that prevail on board a destroyer or torpedo-boat at sea, is much required. See pages 28 and 29.

THE PEICHL compass is the invention of an officer of the Austro-Hungarian Navy of that name. In protected stations, such as in conning towers and between decks, the quadrantal error* for a 10" Thomson's compass amounts to from 16° to 26° requiring 18" to 24" spheres for its correction, the size of the spheres almost prohibit their use in the confined space of a conning tower, the difficulty with regard to space might be lessened by using a 6" compass, but the remaining difficulty of the low directive force of any compass in such a position would not be removed.

In the corrector † proposed by Chevalier Peichl with soft iron rods, the directive force is increased, spheres and Flinders bar are not used, the compass with its corrector is reduced to moderate and serviceable limits: the drawbacks, although they hardly deserve that name, are the adjustment of the corrector on change of latitude, and unless the suspension be perfect, the introduction of a heeling error. The corrector consists of two metal discs, placed one above the other, containing thirty-two soft iron bars movable in opposite directions around the compass bowl, the inner ends of which are from 1 to 1½ inches in distance from the ends of the compass needles and form an ellipse, whilst their outer ends form a circle, the proximity of the needles to the correctors induce magnetism on the latter, and as previously mentioned, this necessitates an adjustment of the corrector on change of latitude, the adjustment is provided for in a simple manner by an index and scale. The moderate space occupied by the Peichl compass and its corrector, and the additional directive force of the former, point to it being a suitable one for conning towers and protected positions between decks, more especially in those portions of the globe where the horizontal force is small.

* For causes of quadrantal error, see page 41.

† The Peichl compass is not described, as it possesses no distinctive features, and a small liquid compass, such as already mentioned, appears preferable. The corrector is fully described in a lecture delivered by Staff-Commander (now Captain) E. Creak, Superintendent of Compasses at the United Service Institution, in 1889.

THE ADMIRALTY COMPASS, now used as a landing one, is well suited for that purpose being an efficient shore compass.

POSITION OF STANDARD COMPASS.—Whatever description of compass is employed, careful consideration should be given to the position of the standard compass. In ships of the Royal Navy it is selected by the Controller's department after consultation with the Hydrographic, due regard being paid to the fact that the ship is a fighting one. In vessels larger than second class cruisers, it is generally placed forward, for convenience when in pilotage waters and manœuvring* generally; it should be easily and rapidly accessible by day and night, sufficiently elevated to obtain allround views, but not placed above slight superstructures, owing to the increased vibrations when steaming at high rates of speed, and the increased shocks on firing heavy guns, the rules issued by the Controller's department to Constructors in H.M. Navy are as follows :—

1. In all designs for the construction of iron ships, a place to be prepared for the Standard compass, and to be shown in the plans. It should be placed near that part of the ship from which she is navigated, and the view therefrom as free from obstructions as possible.

2. No iron to be placed within 5 feet of it; 7 feet is better.

3. To be as far as possible from the ends of elongated masses of iron, especially if vertical, such as funnels, ventilators, masts and conning towers.

4. No iron, subject to occasional removal, should be placed near the compass so as to affect it.

5. In all electrical installations† care should be taken that no disturbing effect be produced on the standard compass.

* In many ships a manœuvring compass is provided in addition to the standard.

† Electrical installation, see page 25.

6. The awnings should be so arranged as to leave the standard compass clear and available for observing the deviation at all times.

POLE OR MAST COMPASSES, have been found very useful in cargo-carrying steamships; they are inconvenient for consultation, and the vessel's vibration and motion are increased in a compass so placed.

PELORUS OR BEARING PLATE.—Where an allround view is unobtainable, the standard compass is supplemented by a Bearing Plate or Dumb Card, those supplied to H.M. ships may be briefly described as follows. A gimbal ring is mounted in gimbals to two short uprights secured to side of its box. The bowl is weighted to keep it horizontal in a seaway, and is balanced by the gimbals to the outer gimbal ring. The upper surface of the bowl consists of two brass plates movable in azimuth by means of raised metal studs. The outer brass plate is marked with lubber lines, carrying sight vane with its pointer, indicating observed bearing; the inner plate is marked to cardinal and inter-cardinal points, and is graduated to degrees. To take a bearing, set inner plate by the lubber's line to ship's course being steered; observe bearing in the usual manner, and the pointer will denote the observed bearing on the graduated inner plate; observe simultaneously when the ship is on her course, this can be assured by placing an observer at the standard compass. The lubber's line must be parallel to the centre fore and aft line of the ship, *i.e.*, it should coincide with an object forward equidistant from the centre fore and aft line of the ship, as the bearing plate is; and the bowl as far as practicable being kept horizontal.

The bearing plate can be utilised in a similar manner for obtaining the deviation of a compass between decks.

MECHANICAL ERRORS in compass card construction, are principally the magnetic axis of the needles on the card are not parallel with the north and south points engraved on the cards, distortion of the card from any cause; prism error,

and the lubber line not in or parallel to the fore and aft line. It should also be borne in mind that pivots become blunted, cups cracked, also pivots are occasionally not sufficiently inserted into their holders to prevent friction ensuing between the upper surface of the card and the under one of the glass verge, the above defects often give rise to reports of a magnetic change in a ship which are really due to mechanical causes.

PEDESTAL FITTINGS.—The wooden pedestal, supporting the compass bowls, the latter are usually of brass, are perforated with a series of holes, fore and aft, and athwartships, forming receptacles for correcting the semi-circular error; * the holes should be horizontal.

The Quadrantal error † is generally corrected by a pair of non-magnetic hollow iron globes, mounted on metal brackets, affixed to the wooden pedestal. Cylinders with spherical ends, in pairs or single, soft iron chain and thin laminæ have been used. Spheres are more symmetrical in their action and their effect can be more easily calculated.

Through the centre of the pedestal is a vertical hole or well; in it is hung by means of a metal chain, ‡ to enable it to be lowered or raised as required, a small metal can or bucket containing usually seven compartments, to prevent the magnets touching one another, in these the vertical magnets for correcting the HEELING ERROR § are placed.

DYNAMO.—A compass, if within the magnetic field of a dynamo will be disturbed, the error varying with change of azimuth. No dynamo should be placed within 35 feet of a Standard compass; with the type of dynamo in general use in H.M. ships, designed for 80 volts at the terminals, the

* See Semi-Circular error, page 40. An improvement would be to place the magnets in a rack, capable of being moved by the observer by means of a screw.

† See Quadrantal error, page 41.

‡ Should the chain part it is difficult to recover the can; an improvement would be to place the latter in a rack.

§ See Heeling error, page 43.

minimum distance of a compass should be 60 feet from a 300 ampère machine, increased to 70 feet from a 400 ampère one; for 600 ampère machines (being armour-clad) the above rules do not apply. A dynamo exerts the least disturbing influence on a compass, when the centre line of its armature produced, intersects the vertical plane passing through the centre of the compass; if the standard compass can be placed at a safe position from the dynamo, this position is not practically carried out; the usual one for a dynamo is with the centre line of the armature shaft either fore and aft or athwartships; the rules given above are as far as practicable carried out with regard to compasses other than the standard.

Having regard to the necessary arrangement of the fittings in a man-of-war, the difficulty in preventing the disturbance of the compass by a dynamo has been considerably lessened by the introduction of an armour-clad dynamo, so named, because it is enclosed in a shield ($\frac{3}{8}$ " plate) of soft iron, which so to speak, gathers the lines of magnetic force into itself, almost destroying the external magnetic field. All the 600 ampère machines are armour-clad, they practically produce no disturbance on a compass 15 feet away, 20 feet may therefore be considered a safe distance, but further experiments will be required before a definite distance can authoritatively be given.

Where the ship's internal fittings compel a departure from the general rules given above, and a disturbing element on the compass is introduced by the proximity of the dynamo, for instance (1) in "Destroyers" where the dynamo (100 ampères) is placed well forward. (2) In the second class cruisers ("Apollo" class), where the two dynamos (300 ampères) are placed one in the after end of each engine room, the standard compass being on the after bridge. (1) The correction is made by an electro-magnet at the foot of the compass pedestal, with its poles opposed to the poles of the dynamo, the ends of the coils of each

electro-magnet are connected directly to the dynamo-terminals, through a fifty-candle power lamp and fuse box, switches are not introduced, the circuits remaining complete through the correctors, except in case of breakage. The fifty-candle power lamps, placed in the dynamo-room, in addition to limiting the current through the magnet-coils, by going out, will indicate a break in the circuit. A preliminary experiment is required to ascertain approximately, the number of turns of wire required in the winding, this being known, the final adjustment is made, by moving them as necessary in the slots in the securing brackets, until it is ascertained by actual observation, that the compass remains unaffected by the dynamo; the correctors are secured in those positions, and permanent connection made at the dynamo terminals.

2. (APOLLO CLASS.) Here two separate disturbing elements exist, acting against or in conjunction with one another, according to whether the poles of the dynamo are symmetrical to the middle line or not, with both dynamos running, in one case the resulting error will be practically nil, and in the other will be the sum of the separate errors.

The shunt coils of the dynamo winding are the principal exciting factors, by passing a current through the shunt coils of a still (non-running dynamo) from a working one it can be excited, therefore, by arranging the shunt coils of the two dynamos, so that a current can be passed through both, from either working dynamo, both will be equally excited and no disturbing influence will be exerted on the compass if the necessary precautions are taken to connect up the shunts, so that the poles of the dynamo are symmetrical to the middle line.

ELECTRIC LIGHTING OF COMPASS.—Owing to the marked desire of many navigating officers to depart from the service fitting and develop patents of their own, it may be as well to briefly touch on systems tried but abandoned. The original method naturally was to replace the oil lamp by an

electric one, the latter was fitted with a flexible cable, from a special kind of switch, with two terminals fixed to the binnacle; this was followed by the inside of the binnacle being white enamelled, the card receiving the reflected light from two 16-candle power lamps, placed under the compass bowl, a lead-cased cable was carried up to each lamp and separate switches were fitted on the binnacle; and the third was the intricate gibbet arrangement, jointed to freely turn on its own axis, at the end of the arm was a metal case with a hole in it, enclosing and of the same shape as a 16-candle power lamp, through the hole in the metal case, a beam of light was projected on to the lubber's line or any portion of the compass card, as the arm was capable of being moved in azimuth.

The present method is practically an improvement of the first, and embodying the results of previous experience. In the position usually occupied by the oil lamp, is placed an electric 16-candle power one, enclosed in a metal cylinder, with a spout* or tube, through which a beam of light passes, sufficient to illuminate the lubber's point and the desired portion of the graduation of the compass card. The current is conveyed to the lamp by a twin cable, protected by phosphor-bronze braiding,† consisting of two conductors of twenty-three wires each of No. 38 L. S. W. G. The lamp with flexible cable and plug piece of the portable connection can be removed when not required; the fixed part of the connection is made watertight by means of a screwed metal case.

The writer proposed in 1897 a method of compass lighting and taking a bearing for small ships or "Destroyers." Briefly, it consisted of two small electric lights (half-candle power) similar to those in use for night

* The writer proposed a portable continuation of the tube, to prevent the diffusion of the light before it reaches the upper surface of the glass verge.

† Steel-braided cable is unsuitable on account of its magnetic properties.

sights of guns, surmounting a small cylinder, containing an 8-candle power electric lamp (16-candle power was intended for practical use), through a narrow slit at each end of cylinder, passed a beam of light sufficient to illuminate 10° of arc of the card, the unit of bearing and (180° from it) being denoted by a dark line: the line joining the electric lights, the cylinder and the centre of the illuminated portions of the card being in the same vertical plane. The instrument working on a foot-plate similar to the one on which the azimuth mirror works; the elaborate fitting and initial expense are against its introduction, but the writer hopes it may form the groundwork for a future system of lighting for that class of vessel.

The following caution should be carefully attended to, as it is an important one, in fitting the cables and wires to a compass pedestal, all conductors should be in pairs, side by side, close together; one in each pair, carrying the current direct and the other the return; so that equal currents proceeding in opposite directions, will counteract each other so far as their action on the compass needle is concerned.

CHAPTER IV.

DEVIATION is the angle included between the magnetic meridian and a vertical plane passing through the poles of the compass needle, or in other words, the difference between the bearings shown by a shore compass (free from local attraction) and one on board ship. Deviation is caused by the disturbing element of iron used in the ship's construction or contained within the ship, varies in different ships and in various positions of the same ship; in addition, the amount varies at each compass, as the ship's head passes through the different points of the compass. Deviation is ascertained by "swinging," that is, causing the ship's head to complete 360° in azimuth, observing the bearing of a terrestrial or celestial object from the standard compass, as the ship's head is slowly placed on each compass point, comparing other compasses with the standard by a bugle note, capable of being heard throughout the ship, or by voice tubes.

The various methods are, first, by a well-defined object, six to eight miles off (according to the size* of the diameter of the circle made by the ship whilst being swung), of which the magnetic bearing is known, and this can be obtained by landing a compass on shore, the selected spot being free from local attraction; and observing the magnetic bearing of the object when in line with the ship. The true bearing can generally be ascertained from an Admiralty chart, if recently surveyed, by applying the variation for the current year to the true bearing, the magnetic bearing is obtained; or the

* The position of the compass in the ship, whether near bow or stern, especially in a long ship will materially affect the diameter of the circle,

horizontal angle measured from the well-defined object to the sun, and its true bearing thus deduced.* With a ship lying any length of time in a harbour, wind and tide combined, will generally cause her to complete an entire circle in azimuth, but when time will not permit of this being done, the ship is usually towed round by a tug and rope hawser. At sea, a ship can be steamed round in a circle, observing the bearing of the sun or a star; two points in line (such as leading marks), lighthouses in line, may be utilised for this purpose; the magnetic bearing is generally known and shown on chart.

The difference between the magnetic and compass bearing will be the deviation, and is called easterly or westerly according to whether the compass north is drawn to the east or west of magnetic north.

Second method—BY RECIPROCAL BEARINGS—is generally used in a small confined harbour or in thick and misty weather. In the former case care must be taken to ascertain that the ship, whilst being swung, will not be affected by the magnetic influence of adjacent ships. A compass, previously compared with the standard, is landed in a suitable spot, free from iron above or underground, or magnetic rocks. To prevent possible errors, the shore compass and standard should be clearly intervisible, and as an additional precaution, watches should be compared. As the ship swings round, she should be steadied on each point and at a preconcerted signal, such as the sudden dipping of a masthead flag, the time noted, and simultaneous bearings taken of the shore compass from standard, and of standard from shore compass. Shortly before the shore compass is likely to be hidden from view by masts, funnel or boats from the standard, a horizontal angle should be measured (from the

* Azimuth tables for true bearing, by the late Staff Commander J. Burwood, R.N., extended by the late Captain J. E. Davis, or the Graphic method of Captain Weir are published by J. D. Potter, 31, Poultry, London. A Variation Chart of the World is published by the Admiralty.

latter spot) between the shore compass and some well-defined object, to prevent an important point being missed. If only one compass is available, before swinging, land that compass obtaining the magnetic bearing of a well-defined object (nearly on a level with the standard is desirable), and at each signal measure the horizontal angle between the standard compass and the previously well-defined object; this will give the magnetic bearing of the former at each observation. The difference between the shore bearing and the ship bearing reversed (180° added) will be the deviation.

In fine weather at sea, in tropical countries, stellar observations are generally employed for ascertaining the deviation.* A circumpolar star at its greatest eastern or western elongation, affords a ready method, as the star is practically stationary in azimuth.†

The deviations are then entered in detail on a form provided for that purpose.

The following points should be attended to, by whatever method the ship is swung; she should not be swung too rapidly, but steadied on each point, because in the construction of a ship, there is an intermediate class of iron, neither soft nor hard, but which parts with its induced magnetism slowly, and should an error be suspected from this cause, the ship should be swung twice, but in opposite directions, and the mean of deviations be used.

In addition, guns near the compass should be stowed for sea, boom boats in their place, boat's davits turned in, and cat davits down. In conning towers, where the top is capable of being raised and lowered, its position should be noted, whether the shutters are open or closed during the

* A difficulty may occasionally occur in manipulating the electric light for stellar observations.

†

$$\text{Sin. az.} = \text{sec. lat.} \times \text{cos. dec.}$$

$$\text{Sin. alt.} = \text{sin. lat.} \times \text{cosec. dec.}$$

$$\text{Cos. hour angle} = \text{tan. lat.} \times \text{cot. dec.}$$

A star can easily be identified if the above simple solutions in right angle spherical trigonometry be previously worked out.

swinging, also when the conning-tower compass is being compared with the standard. Colliers or water-tank vessels should not be alongside during swinging.

If a point be missed, it is usually interpolated, but if the errors are large they can be plotted on prepared paper ruled in small squares, in a curve, or on Napier's diagram; the latter is a straight line, divided into 32 or 360 equal parts, representing the points or degrees of the card; the deviations are laid off on lines, cutting the vertical one at an angle of 60° , easterly deviations on the right, and westerly deviations to the left of the vertical line. On the Table of the deviations should be placed the position, size, and number of the fore and aft, athwart and vertical magnets.

Below is a specimen of a Table of deviations obtained by a ship swinging from a buoy with a distant object, and one underweigh with the sun :

H.M.S. "WARSPITE," <i>Sheerness</i> .			H.M.S. "AGINCOURT," <i>Nore</i> .			
Magnetic bearing of Jezreel Tower, S. $78^\circ 20'$ W., distant 8 miles.			Apparent time of place has been omitted.			
Direction of Ship's Head by Standard.	Bearing by Compass of Jezreel Tower.	Deviation.	Direction of Ship's Head by Standard.	Magnetic † Bearing of the Sun.	Bearing by Compass of the Sun.	Deviation.
North	S. 78 00 W.	0 20 E.	North	S. 68 30 W.	S. 68 30 W.	0 00
N.N.E.	S. 79 50 W.	1 30 W.	N.N.E.	S. 77 00 W.	S. 76 00 W.	1 00 W.
N.E.	S. 68 50 E.*	1 10 W.	N.E.	S. 76 30 W.	S. 76 00 W.	0 30 W.
E.N.E.	S. 69 00 E.*	1 00 W.	E.N.E.	S. 76 00 W.	S. 75 30 W.	0 30 W.
East	S. 69 00 E.*	1 00 W.	East	S. 75 30 W.	S. 75 00 W.	0 30 W.
E.S.E.	S. 77 00 W.	1 20 E.	E.S.E.	S. 74 00 W.	S. 75 00 W.	1 00 E.
S.E.	S. 77 45 W.	0 45 E.	S.E.	S. 72 30 W.	S. 74 00 W.	1 30 E.
S.S.E.	S. 78 00 W.	0 20 E.	S.S.E.	S. 71 30 W.	S. 73 30 W.	2 00 E.
South	S. 77 45 W.	0 45 E.	South	S. 71 00 W.	S. 73 00 W.	2 00 E.
S.S.W.	S. 77 30 W.	0 50 E.	S.S.W.	S. 70 40 W.	S. 72 00 W.	1 20 E.
S.W.	S. 78 50 W.	0 30 W.	S.W.	S. 70 40 W.	S. 71 30 W.	0 50 E.
W.S.W.	S. 80 00 W.	1 40 W.	W.S.W.	S. 70 20 W.	S. 71 00 W.	0 40 E.
West	S. 80 00 W.	1 40 W.	West	S. 69 40 W.	S. 70 40 W.	1 00 E.
W.N.W.	S. 79 45 W.	1 25 W.	W.N.W.	S. 69 00 W.	S. 70 00 W.	1 00 E.
N.W.	S. 79 00 W.	0 40 W.	N.W.	S. 68 00 W.	S. 69 30 W.	1 30 E.
N.N.W.	S. 78 00 W.	0 20 W.	N.N.W.	S. 67 30 W.	S. 68 45 W.	1 15 E.

* Jezreel Tower obscured, Minster Church observed.

† It is usual in practice, before swinging, to convert the sun's true into magnetic bearing for the period of time, which will probably be occupied in adjusting and swinging the ship.

In addition to the above methods of ascertaining the deviation by bearings of visible objects, several instruments have been devised for correcting the error of a compass, without bearings, an invaluable assistance in thick weather. The inventions of Sir William Thomson (Lord Kelvin),* Dr. Waghorn deflectors,* and Chevalier Peichl Control compass,† are for that purpose. If the directive forces acting on the compass were equalised, there would be no deviation; but if an instrument were devised capable of measuring the directive force of the compass needle with the ship's head on the magnetic cardinal points, their comparative strength would be known and could be equalised by fore and aft and athwartship magnets. The horizontal force acting on the compass, due to the hard iron in the ship, will either increase or lessen the normal amount, according to whether it is acting with or against the horizontal component of the earth's magnetic force; in the former case the angle of deflection produced by another magnet of a certain power, at a certain position and distance on the compass needle, will be smaller than in the latter case, because the smaller the directive power of the needle, the larger the deflection. Now, supposing with a certain magnetic force we always deflect the compass needle 90° on the four cardinal compass points, it would be found that increased or decreased magnetic power would be required, for if only the normal force were exercised on all points, the directive force would be equal, and there would be no deviation. A deflector measures the augmented or diminished power, and enables a mean to be taken, at which the deflector is set, the 90° deflection being obtained by moving the fore and aft and athwartship magnets. In the above explanation, the quadrantal error‡ is supposed to have already been corrected,

* Fully described in 'Deviation of the Compass,' by Professor Reinold & Dr. Waghorn. Published by Henry Richardson, 4, Church Street, Greenwich.

† Described by Staff-Commander (now Captain) Creak in No. CXVII. of the Journal of the Royal United Service Institution.

‡ For Quadrantal error, see page 41.

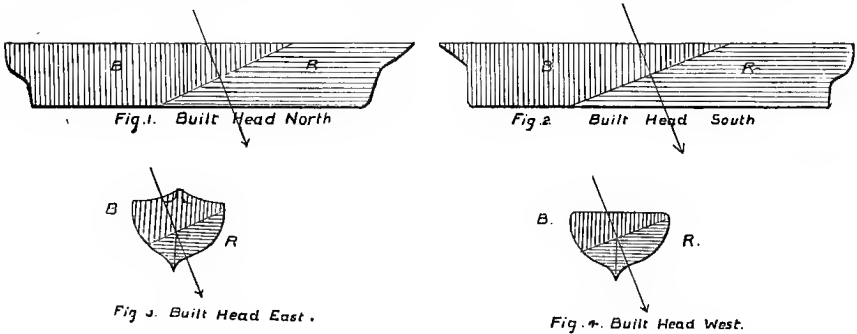
and as after being corrected it remains constant for all latitudes, it is unlikely that the deflector would be used for the purpose of correcting quadrantal error, but the normal deflection (90°) can be obtained by moving the quadrantal spheres.

Chevalier Peichl Control compass is based on the fact that when a dip circle is placed in the magnetic meridian, the minimum dip is obtained. The principle only on which the above deflectors act is briefly stated; it requires an expert practical observer to use them with advantage, but in his hands they have given satisfactory results.

We will now proceed to inquire into the effect of the iron in a ship on the compass, the general conclusions to be arrived at, and any known disturbing elements, whether regular or irregular. In the early wood-built ships, with a compass in the centre line of the ship, placed on the quarter-deck, the points of no deviation were with the ship's head near north and south, and the maximum deviation when east and west, easterly deviation with the ship's head in the eastern semi-circle, and westerly when in the western semi-circle, but becoming reversed in southern magnetic latitudes. In wood-built steam-vessels the same general features occurred, except the points of maximum and minimum deviations were near, but not at the cardinal points, the deviation usually becoming reversed in southern magnetic latitudes. In both cases a Flinders bar could have been employed, if considered necessary. In the composite and early iron-built ships, the points of no deviation, instead of being the same as in wood-built steam-vessels, were chiefly dependent on the magnetic direction in which the ship was built—the ship becoming a magnet, or, strictly speaking, the various parts and fittings of the ship becoming a series of small magnets with their red and blue poles parallel, the magnetism being more or less permanent, according to the degree of hardness of the iron used and the amount of mechanical violence to which it is subjected, but it is more

convenient to regard the ship as a whole when dealing with permanent magnetism. The ship, whilst being built, becomes a magnet from the induced magnetism of the earth; the greatest force is the line of the earth's dip at the place, being also the points of maximum and minimum directive force of the compass needle; there is a neutral line at right angles to the dip. Below is shown the distribution of magnetism for an iron ship built in England on the cardinal points (Figs. 1, 2, 3, 4).

The disturbance caused by permanent* magnetism on the compass needle can be clearly illustrated by placing a magnet exercising less power than the horizontal component



of the earth's force near a small compass, and causing the magnet to complete a revolution around the compass; the disturbances produced will depend on the relative values of earth and magnet. With the Standard compass placed well forward, and the introduction of iron turrets, conning-towers, masts, chart-houses, superstructures, and in the ship's fittings generally, the direction in which the ship was built is no longer clearly discernible, but is lost in the disturbances produced by the surrounding iron. It is customary, where

* In order to prevent confusion in the mind of the reader between "permanent" and "sub-permanent" magnetism, the former is generally used in the sense of being the opposite of transient magnetism. The expression sub-permanent magnetism was introduced by the late Sir G. B. Airy to show the lesser degree of permanency in the so-called permanent magnetism of an iron ship to that possessed by a magnet; both change, but in the latter case very slowly.

practicable, to place the armour-plates in position, and complete the ship in the reserve with the ship's head in an opposite direction to her building one, with a view to reduce her semi-circular deviation,* the magnetic direction of the ship will then be intermediate between the direction of the ship's head whilst being built, and that whilst being completed for commission. It should be borne in mind the greatest change in the magnetic character of a ship occurs after launching until she is commissioned, but now that ships are subjected to force, natural, and consumption steam trials, in addition to gun trials, it may be fairly assumed that, on commissioning, the magnetic character of the ship has become fairly stable.†

SUB-PERMANENT‡ magnetism produces deviation in a similar manner to the permanent, but it may be increased or diminished, or even reversed, in sign. In large ships, with a Standard compass properly placed, the change is small, but in "Torpedo-boats" and "Destroyers" it has varied 6° in a comparatively short space of time. It is due to that intermediate class of iron neither hard nor soft, but possessing some of the characteristics of both, and is liable to change owing to lapse of time, or suddenly reversed by severe shocks, such as gun-firing (the disturbance caused by heavy gun-firing might be diminished by firing the guns with the ship's head in opposite directions), the error from this cause may disappear in an hour, or the return to the normal deviation may be gradual, occupying some days. An intermediate class of soft iron may be temporary magnetised by induction through the vibration of a ship when steaming at high speeds; steaming at ordinary speed against a head sea; docking; steaming, or remaining on a given course for a

* Semi-circular deviation, see page 40.

† In the mercantile marine the "stable period" is generally arrived at within the year, and nearly so after a few months' active service.

‡ See note * on previous page. Sub-permanent is used in these pages to denote an Unstable period. Unstable magnetism would be a better term than Sub-permanent.

considerable time these disturbances are usually called Retentive (more correctly Transient) error and Gaussin error.

Gaussin error should always induce great caution and watchfulness, because, if after several days' steaming on one course, the course is suddenly altered to one at right angles to the former one, perhaps in thick weather, the danger is that the disturbance does not begin to take effect on the needle until the second course is being steered, although it is gathering in strength whilst on the original course; and again, the disturbance gradually diminishes whilst on the second course, but not according to any known law. No corrector, at present, exists for this error, but a navigating officer, by carefully watching the effects produced by the above causes in fine weather, will be in a position to predict in a general manner the probable disturbance in thick weather, and this will give the navigating officer greater confidence.* The disturbance is greater in high magnetic latitudes than in low, and when the original course is east and west than when north and south, the tendency being for the ship's head to be drawn in the direction of the original course. In preparing a Deviation table by swinging, Gaussin error can be eliminated by swinging first to starboard and secondly to port.† The following is taken from the instructions for Sir William Thomson's compass: * "If the ship underweigh is steamed round on the different courses, the amount of the 'Gaussin error' may generally be greater than if she is hauled round by warps; but we must not be sure that it will be so, because the *shake* of the screw, which enhances the magnetisation on the east or west courses, may shake it out again before the observation is made on the north and south courses."‡

* See instructions for Sir William Thomson's (Lord Kelvin) compass. James White, 209, Sauchiehall Street, Glasgow.

† Captain Mayes states that the "*Defence*" swung in 1865 in this manner, the maximum difference was 3° on the north and south points.

‡ A Gaussin error of 3° developed by second-class cruisers whilst lying alongside the basin wall at Chatham during the period they were in the

TORPEDO-BOATS AND DESTROYERS are supplied with the improved liquid compass as a Standard, placed in a selected position, but only five feet * from a thin iron or steel structure, subject to excessive vibration, and an occasional concussion from firing of guns. It is, therefore, to be expected that their magnetism, whether permanent or sub-permanent, will vary considerably more than in larger ships. In Torpedo-boats, the close agreement of the deviations, after considerable time has elapsed, is remarkable, but it is possible that their magnetic character at sea may alter, reverting to the normal (harbour) character after being in harbour some days. In some of the early "Destroyers," a rapid change in the deviation took place, owing to an equally rapid change in the sub-permanent magnetism of the ship; but with the increased height of the standard compass from the deck, this error has been diminished, but constant watchfulness and observation should be exercised after guns are fired, and the disturbances described previously under "Transient error" apply with increased force to "Destroyers" and "Torpedo-boats," but if a careful sea magnetic record were kept in "Destroyers," under the varying circumstances described above, it is probable some practical rules could be deduced therefrom, and issued for the benefit of their navigating officers.

There is an irregular disturbing element to the compass outside the ship, viz., the land itself, not above the surface of the water, but below it; for many years past, it has been reported that the compass was disturbed on passing islands, points, etc.; but the reports were discredited, as owing to the laws of magnetic attraction, even if the nearest visible land were composed of magnetic ore, it could not exercise any appreciable disturbing effect on the compass at the distance it was being passed. The Surveying schooner

Fleet Reserve, generally disappeared on arrival at Sheerness under steam, a distance of $8\frac{1}{2}$ miles.

* In Destroyers this distance is now increased to 6 feet.

Meda,* in 1883–85, by careful observations off the island of Bezout—north-west coast of Australia, the land being distant about three miles—showed that the source of the disturbance was submarine, viz., that the bottom travelled over (although in eight fathoms water), was sufficiently magnetic for a mile to disturb the needle 30° † Similar disturbances have been reported from Labrador, Madagascar, Solomon Islands, Iceland, Java, Odessa Bay, and Isle de Los, West Coast of Africa; an extra caution should therefore be exercised by the navigator when in those localities.

SEMI-CIRCULAR ERROR is so called from being easterly (+) in one semi-circle, and westerly (–) in the other. The larger portion is caused by the permanent magnetism of the ship (the small changing portion in the sub-permanent magnetism may be expected to diminish very slowly with lapse of time, and for which no corrector has been found). As previously mentioned, there will be points of no deviation, or neutral points, 180° apart, the deviation for any point will be the maximum deviation multiplied by the sine of the azimuth, from the neutral point of the disturbed compass. On change of geographical position, this portion will vary inversely as the earth's horizontal force, the permanent magnetism exercising least force at the magnetic equator, and again increasing, according to the rule given above, as the ship proceeds south, or increases her magnetic latitude. This force may be considered as acting in the ship in a fore and aft and athwartship direction, and the errors produced are therefore corrected by permanent magnets placed in those positions in the binnacle. The remaining portion of the semi-circular deviation is caused by induced magnetism in vertical soft iron. In England (northern

* Commanded by Staff-Commander (now Captain) J. E. Coghlan.

† Captain W. Usborne Moore, in H.M.S. *Penguin*, re-examined this locality, obtaining a maximum disturbance of 55° , the disturbed area remaining about the same.

magnetic latitudes), the lower ends possessing red, and the upper blue magnetism, varying as the tangent of the dip,* disappearing at the magnetic equator; but as the ship proceeds from there, south, blue magnetism is developed in the lower ends, and red in the upper, increasing in strength according to the tangent of the dip. With a compass in the centre line of the ship, the iron is fairly symmetrically distributed with the fore and aft line, and the error is therefore corrected by vertical soft iron (FLINDERS BAR) placed in the centre, of the fore or aft side of the compass as necessary. As a general rule with compasses placed well forward or aft; the disturbing influence of vertical iron is abaft or forward of compasses so placed; the Flinders bar is therefore placed on the opposite side of the compass to which the disturbing influence is exerted, in order to counteract it. Cases may occur where the disturbing influence of the ship's vertical iron, on the compass, may be dominated or controlled by the proximity of a conning tower, funnels, iron masts, etc. From the foregoing remarks, it will be readily seen that, if a ship, after rough adjustment, proceeds to a place with greater horizontal force, increased power in fore and aft magnets will be required; if to greater vertical force, increased Flinders bar will be required.†

QUADRANTAL ERROR is due to induction in horizontal soft iron,‡ continuous or non-continuous, fore and aft and athwartships, and is so called from its being alternately easterly and

* See page 18 for connection between horizontal, vertical, total force and dip.

† Lord Kelvin's (Sir William Thomson) Flinders bar is about 24 inches long, composed of cylindrical iron in separate pieces of unequal length, the longest being on top, which is kept at a distance of 2 inches above and about 9 inches from the centre of the compass. To keep the vertical height constant, duplicate pieces are made of wood and placed at the bottom of the brass tube containing the Flinders bar.

‡ Non-continuous usually reckoned +, and continuous -. A ship wholly armour-plated will tend to diminish the quadrantal error and strongly diminish the directive force. A ship with unarmoured ends, but with armour bulkheads near the compass, will produce a large quadrantal error, but only slightly diminish the directive force. (See Fig. 8.)

westerly in the four quadrants ; its effect can be practically shown by carrying a bar of soft iron in the same horizontal plane with and around a small compass ; at the cardinal points it will exercise no disturbing influence on the needle, and the maximum points of disturbance will be at the inter-cardinal points. In swinging a ship from north through east, the deviation is usually easterly (+) in the N.E. and S.W. quadrants and westerly (−) in the S.E. and N.W. quadrants, *i.e.* +, −, +, −. Continuous masses athwartships and non-continuous masses in the fore and aft line cause an easterly (+) deviation in the N.E. quadrant, and continuous masses in the fore and aft line and non-continuous athwartships produce a westerly (−) one in the same quadrant—the iron beams used in the ship's construction being the principal source of quadrantal error, it is therefore connected by detached soft iron masses athwartships. The usual correctors are hollow* non-magnetic cast-iron spheres, of a minimum thickness of an inch, mounted on brass brackets, the spheres are equidistant from, and their centres in the same horizontal plane with the centre of the needles.† With a compass, not in the midship line ; or a compass in the midship line, with iron unsymmetrically distributed, such as turrets *en échelon* ‡ ; the spheres being still equidistant and in the same horizontal plane as the compass needles, must be placed at an angle with the athwartship line. In case, when swinging from north through east, a − (negative) § quadrantal error is found, *i.e.*, −, +, −, +, it may arise from over-correcting a previous + (positive) error ; or with a mast or pole compass, when it is placed near the centre of the ship's length ; but the amount in each case will be small.

* Hollow spheres are employed on account of their lightness ; their value in correcting quadrantal error is for practicable purposes equal to solid spheres, provided the thickness of their shell exceeds an inch.

† In using the expressions vertical and horizontal refers to when the ship is on an even beam, *i.e.*, upright, unless the contrary is expressly stated.

‡ H.M.S. *Inflexible*.

§ − D was often found in shallow wood-built screw ships.

QUADRANTAL ERROR alters slightly by lapse of time, but will not vary on change of magnetic latitude ; the increased or decreased strength of the induced magnetism in horizontal soft iron (which is the cause of the quadrantal error) will vary in the same proportion to the increased, or decreased horizontal force directing the needle, and the resultant of the forces will not vary in direction ; these remarks do not apply to the PEICHL compass corrector, its soft iron rod correctors acquire temporary induced magnetism from the needles and are altered on change of magnetic latitude. Quadrantal spheres increase the needles' directive force on east and west courses.

HEELING ERROR.—Hitherto the deviation has been of a ship on even beam, that is upright, and the vertical component of the ship's permanent magnetism caused no deviation. If a ship, roughly connected for quadrantal error, is heeled, the vertical force being no longer so, will cause an error (1) acting upwards or downwards,* according to the direction in which the ship was built, the attraction of the needle to the windward or leeward side depending on the position of the compass in the ship. (2) Horizontal soft iron, consisting of beams, decks, etc., and horizontal detached masses become inclined, receiving temporary induced magnetism from the earth's vertical force ; their upper ends with blue and lower ends with red magnetism in northern, and upper ends red and lower blue in southern magnetic latitudes.† The continuous and detached horizontal soft iron will act in an opposite direction, and in addition the quadrantal spheres will tend to compensate a portion of the heeling error due to continuous horizontal soft iron. The above are the principal causes of the heeling error, and it will be readily seen that they exercise their greatest force on the needle when the ship's head is compass

* Usually marked — if acting upwards, and + if downwards.

† Changing their signs on crossing the magnetic equator and increasing in power as higher magnetic latitudes are reached.

north and south, being then at right angles, and their minimum when parallel, *i.e.*, with the ship's head compass east and west. The Heeling error is usually counteracted by magnets placed end on, vertically below the centre of the compass ; it is better to employ two or three small magnets instead of a large one, increasing their number if necessary in lieu of decreasing the distance between the magnets and the compass.* Vertical induction in vertical soft iron (iron stanchions, funnels, masts) the direction and intensity will vary when the ship heels, this change is generally merged into that due to the ship's vertical force acquired whilst building, and they are treated as one. Vertical masses above the compass act in a contrary manner to similar ones below the compass, thus tending to diminish the heeling error or the proximity of a mast or funnel to the compass, may counteract and exceed the combined disturbances of the vertical force of the ship and vertical soft iron. This error can be corrected by a soft iron bar, or by raising the upper end of the Flinders bar above the level of the compass.

A small heeling error not usually corrected is caused by the (soft iron) of the keel, inducing a transient vertical force, which has no disturbing influence when the ship's head is on the east and west points ; it is therefore desirable to correct the heeling error when on one of those points. Practically what is done in correcting the heeling error is to make the vertical and horizontal forces at the compass bear the same ratio as the vertical and horizontal forces do on shore. It should also be borne in mind that the healing error is not wholly corrected, but the error is brought within reasonable limits.

HEELING CO-EFFICIENT is the amount of deviation caused by 1° of heel when the ship's head is north or south by the ship's compass, the amount then being at its maximum ; and is found for any other azimuth by multiplying it by the

* Alters on change of magnetic latitude, *i.e.*, of vertical force.

cosine of the azimuth measured from the points of maximum disturbance.

CONSTANT DEVIATION is the amount the easterly (+) deviations exceed the westerly (−) or *vice versâ*. In a properly placed compass it is generally under 1° , but in a compass out of the centre line of the ship and near unsymmetrically placed soft iron, it will exceed that amount. It does not change with the magnetic latitude and remains constant on all courses, in a steering compass it can be corrected by altering the lubber's line. A false or apparent constant deviation may be due to instrumental errors in the compass or azimuth mirror, or from an incorrect magnetic bearing.

CHAPTER V.

IN the previous chapters, how to obtain the deviation and the causes of it have been explained. We will now propose to analyse the deviation to show the constituent parts of the error. All forces acting on the compass needle may be resolved in horizontal and vertical planes passing through the centre of the needles; as already shown the vertical forces will produce no errors so long as the ship remains upright; the horizontal force can be divided into two forces, one acting in a fore and aft, and the other in athwartship direction (Fig. 5).^{*} To analyse a deviation table, the late Mr. Archibald Smith represented their constituent parts by the letters A, B, C, D, and E, called co-efficients; using the following equation, if δ be the deviation for any compass course θ , reckoned from 0 to 360, through east—

$$\delta = A + B. \sin \theta + C. \cos \theta + D. \sin 2 \theta + E. \cos 2 \theta.$$

The co-efficients shown in degrees and minutes represent the maximum error produced separately by the disturbing forces of the ship's magnetism. If the errors are small, the forces are considered proportional to the errors they produce, but strictly, they are proportional to the sines of those errors.

A is the constant[†] error (real) due to the horizontal induction in soft iron unsymmetrically placed, and is ascer-

^{*} In Fig. 5, O R represents the combined disturbing horizontal force of the ship's iron on the compass. It can be resolved into the forces O A (C) and O F (B).

[†] For Constant error, see page 45.

tained by adding algebraically the deviations (easterly deviations +, westerly deviations -) on the four cardinal points, and dividing their sum by four.

B and C represent the semi-circular * error ; B is called + when the force is towards the bow, and - when towards the stern ; C is called + when the force is towards the starboard side, and - when towards the port side. B is approximately the deviation at east ; or west with its sign changed, or the mean of the two. C is approximately the deviation at north ; or the deviation at south with its sign changed, or the mean of the two. B and C represent, respectively, the magnetic fore and aft, and athwartship forces of the ship.

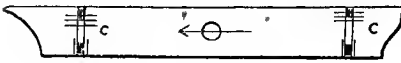


FIG. 6.

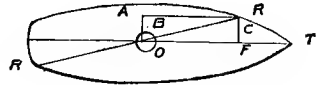


FIG. 5.



FIG. 7.

In Fig. 6 (ship's head north), B will have no disturbing effect, as it is acting in line or parallel to the direction of the needle ; but the C force, being at right angles, will be at its maximum.

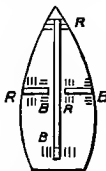
In Fig. 7 (ship's head east), the force of B being at right angles, will be at its maximum and C at its minimum, the force being parallel to the needle. As the forces producing semi-circular error may be considered porportionate to the deviation that takes place. Semi-circular error is expressed by the second and third terms of the equation : $B \sin \theta + C \cos \theta$.

D and E are the component parts of the quadrantal error.† D is the mean value of the deviations at N.E. and S.W. ; or the deviations at S.E. and N.W., with their signs changed, or the mean of both means ; and is the maximum

* For Semi-Circular error, see page 40.

† For Quadrantal error, see page 41.

quadrantal error caused by temporary induction in horizontal soft iron symmetrically placed. E is the maximum quadrantal error caused by temporary induction in horizontal soft iron unsymmetrically placed, is closed allied to A (real); and it is found by adding algebraically the deviations on the four cardinal points, reversing the signs on east and west, and dividing their sum by 4.



D FIG. 8.—Horizontal soft iron symmetrically placed. Continuous masses in the fore and aft line and non-continuous athwartships. Cause — (westerly) error in N.E. quadrant.



E FIG. 9.—Horizontal soft iron unsymmetrically placed. Turrets *en échelon*.

Usually for a standard compass, E is very small in amount and remains uncorrected, but in a ship with turrets *en échelon*, and in protected stations between decks with the compass out of the centre line of the ship, it may be necessary to compensate for the error, by placing the line joining the centre of the quadrantal spheres at an angle β with the athwartship line, so that $\tan 2\beta = \frac{E^*}{D}$. In a similar manner in "Destroyers," where the poles of a dynamo make an angle with the athwartship line, the soft iron corrector in the deck is placed at a like angle. Quadrantal error will be expressed by the 4th and 5th terms of the equation: $D \sin 2\theta + E \cos 2\theta$,† and—

$$\delta = A + B. \sin \theta + C. \cos \theta + D. \sin 2\theta + E. \cos 2\theta.$$

Below is an example of obtaining the co-efficients ‡ from

* 'Deviation of Compass,' by Professor Reinold and Dr. Waghorn, page 19.

† For mathematical proof, *Ibid.*, page 17.

‡ The method of obtaining the co-efficients from deviations observed on 32 or 16 points of the compass is shown in the Admiralty Manual. The general method is the same.

the deviation table of H.M.S. *Warspite* (already given at page 33), from eight points, viz., on North, N.E., East, S.E., South, S.W., West, and N.W. Mark six columns I, II, III, IV, V, and VI; place the deviations on the first four points under I, and the remaining four under II, with their proper signs prefixed.

III will be half the sum (algebraically) of lines under I and II.

IV will be half the sum (algebraically) of lines under I and II, but the signs in lines under II must be changed.

Under V and VI, place the values under III after being multiplied by the natural sines and cosines (0° and 45°).

Half the algebraic sum under V and VI are the co-efficients B and C.

Mark four columns $1A$, IIA , $IIIA$, and IVA , the two upper lines under III place under $1A$, and the two lower under IIA .

Place half the algebraic sum under $IIIA$ and again under IVA , but in the latter case the signs under IIA must be changed.

The upper line will be E and the lower D.

Half the algebraic sum under $IIIA$ will be A.

I.	II.	III.	IV.	V.	VI.
$\begin{smallmatrix} 0 & / \\ + & 0 & 20 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ + & 0 & 45 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ + & 0 & 32 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ - & 0 & 12 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ 0 & 00 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ - & 0 & 12 \end{smallmatrix}$
$\begin{smallmatrix} 0 & / \\ - & 1 & 10 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ - & 0 & 30 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ - & 0 & 50 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ - & 0 & 20 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ - & 0 & 14 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ - & 0 & 14 \end{smallmatrix}$
$\begin{smallmatrix} 0 & / \\ - & 1 & 00 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ - & 1 & 40 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ - & 1 & 20 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ + & 0 & 20 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ + & 0 & 20 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ - & 0 & 00 \end{smallmatrix}$
$\begin{smallmatrix} 0 & / \\ + & 0 & 45 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ - & 0 & 40 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ + & 0 & 02 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ + & 0 & 42 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ + & 0 & 29 \end{smallmatrix}$	$\begin{smallmatrix} 0 & / \\ - & 0 & 29 \end{smallmatrix}$
				$+ 0 \ 49$	$2) - 0 \ 55$
				$- 0 \ 14$	$- 0 \ 27 \ C.$
				$2) + 0 \ 35$	
				$B \text{ is } + 0 \ 17$	

IA.	IIA.	IIIA.	IVA.
° ' ,	° ' ,	° ' ,	° ' ,
+ 0 32	- 1 20	- 0 24	+ 0 56 is E
- 0 50	+ 0 02	- 0 24	- 0 26 is D
		- 0 48	
		- 0 24 is A.	

To obtain the deviation from the co-efficients is to make use of the late Mr. A. Smith's formula at the commencement of this chapter.* This following formula † will give B, C, D, by observations made in one quadrant; A and E are assumed to be nil. The letters NE, N, and E, prefixed to δ , refer to the deviation with the compass, respectively, on those points.

$$\begin{aligned}
 \text{N.E. quadrant. } D &= \frac{\sin 45^\circ \times \sin N E \delta - \frac{1}{2} (\sin N \delta + \sin E \delta)}{\sin 45^\circ \times \cos N E \delta - \frac{1}{2} (\sin N \delta - \sin E \delta)} \\
 B &= (1 + D). \sin E \delta. \quad C = (1 - D). \sin N \delta \\
 \text{S.E. } & D = \frac{-\sin 45^\circ \times \sin S E \delta + \frac{1}{2} (\sin E \delta + \sin S \delta)}{\sin 45^\circ \times \cos S E \delta - \frac{1}{2} (\sin E \delta - \sin S \delta)} \\
 B &= (1 + D). \sin E \delta. \quad C = -(1 - D). \sin S \delta \\
 \text{S.W. } & D = \frac{\sin 45^\circ \times \sin S W \delta - \frac{1}{2} (\sin S \delta + \sin W \delta)}{\sin 45^\circ \times \cos S W \delta - \frac{1}{2} (\sin S \delta - \sin W \delta)} \\
 B &= -(1 + D). \sin W \delta. \quad C = -(1 - D). \sin S \delta \\
 \text{N.W. } & D = \frac{-\sin 45^\circ \times \sin N W \delta + \frac{1}{2} (\sin W \delta + \sin N \delta)}{\sin 45^\circ \times \cos N W \delta - \frac{1}{2} (\sin W \delta - \sin N \delta)} \\
 B &= (1 + D). \sin W \delta. \quad C = (1 - D). \sin N \delta
 \end{aligned}$$

The directive force of the needle in the earlier ironclads was found to have been reduced about a fourth in amount; with the introduction of conning towers and compasses placed near and inside them, the directive force was still further reduced, until it was only one-fourth of the amount in comparison with the shore. In previous paragraphs referring to permanent magnetism ‡ and semi-circular ‡ error, it was shown that the effect of the permanent magnetism on the

* See Admiralty Manual, page 27.

† *Ibid*, page 38.

‡ See pages 36 and 40 respectively.

directive force of the needle is to augment its normal amount on one point and to decrease it by an equal amount on the opposite one ; 180° removed from one another, according to whether it is acting with or against the earth's force ; the mean value remaining unaltered ; it is, therefore, apparent the diminution in the directive force of the needle on board ship must be due to some other cause, viz., to horizontal induction in soft iron, and its effect can be clearly illustrated by placing a compass inside a conning-tower with 12" plating, the directive power would be 0.2 (assuming the earth's horizontal force to be 1), if the plating were increased in thickness until it was one-tenth the diameter of the conning-tower, the directive power of the needle would be destroyed.

In a general magnetic sense, the cause may be illustrated in this manner—if the conning-tower were made of wood (Fig. 10), the lines of force would be parallel and equidistant,

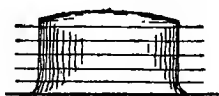


FIG. 10.*

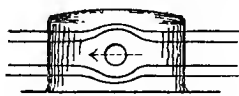


FIG. 11.*

the magnetic field being uniform, and the compass needle unaffected ; but (Fig. 11) substitute soft iron for wood, the magnetic field is no longer uniform, lines of force are no longer parallel and equidistant, through the lines of force travelling through the iron instead of the air, the former being more permeable, *i.e.*, offering less resistance to the lines of force.†

In an iron ship, the decks, bulkheads and beams (continuous iron) appear to attract the lines of force and lessen the directive power of the needle, but detached masses

* In the south of England these lines would be inclined to the horizontal plane at an angle of $67^\circ 20'$

† The placing of armour-plates around the ship's dynamos will probably throw some additional light on this subject.

(quadrantal spheres)* increase the mean directive force, by increasing it when north and south, and decreasing it by half the augmented amount when east and west.

The earth's horizontal force in the south of England is assumed to be 1. The mean value of the horizontal force in the ship for a complete circle in azimuth is called λ (lambda). The proportion between the earth's and compass horizontal force will be inversely as the square of the number of seconds occupied by a needle in making the same number of vibrations on shore, and when in the position of the compass. In England a needle† usually makes ten vibrations in nineteen or twenty seconds, supposing the needle to make ten vibrations in twenty seconds on shore, and on being placed in the compass pedestal makes the same number of vibrations in twenty-eight seconds :

$$H' \text{ (Compass horizontal force)} = H \text{ (Earth's horizontal force)} \times \frac{20^2}{28^2}$$

$$H' = 1 \times \frac{400}{784} = 0.51,$$

Showing that in that direction of the ship's head the ship's force is acting against the earth's force; but if the time of making the same number of vibrations be decreased to sixteen seconds, it would shew that the ship's and earth's horizontal force were acting in conjunction, and H' would be 1.5. H' (being at the compass), is composed of the

* See pages 41 and 43.

† The needle should be about three inches long, flat and pointed, with a jewelled cap working on a pivot; the latter should fit the pivot holder in compass bowl. The needle is vibrated in the horizontal plane by means of a weight placed to counteract the dip. It should be used in a closed box or compass bowl to prevent the needle being disturbed by the motion of the air, the arcs of vibration should be as small as convenient to lessen the effects of friction and resistance of the air, and should not exceed an arc of 45° at the commencement. The horizontal components may be compared by the deflections produced by a magnet placed at right angles to the needle.

horizontal components of the earth, and the ship's permanent and induced magnetism in the direction in which the needle points (*i.e.*, the compass north), to ascertain H' for magnetic north, the observed horizontal force must be multiplied by the cosine of the deviation. λ can be ascertained by observations on four or more equidistant true or magnetic azimuths, from the mean of several values of $\frac{H'}{H} \cos \delta$, or the mean of the forces at N and S.

In the previous chapter, the causes of semi-circular error have been stated; and in the present one that the semi-circular error can be represented by the co-efficients B and C, and that B is composed of (P), the force acting in the fore and aft line due to the permanent magnetism of the ship, its effect changing inversely as the earth's horizontal force and (*c*) due to vertical induction in soft iron, varying with the tangent of the dip.*
$$B = (c \times \tan. \text{dip} + \frac{P}{H}) \times \frac{1}{\lambda}$$

At the magnetic equator (no dip) *c* will be nil, and if B and C were corrected by permanent magnets, the change thereafter, when proceeding to higher magnetic latitudes would have to be corrected by Flinders bar. For a similar reason if it were found that a Flinders bar was not required in England, it would be required still less in the principal portions of the globe visited by men-of-war, where the horizontal force is greater and the dip less than in England, the exceptions being Norway and Iceland on the Home, the neighbourhood of Behring Strait on the Pacific station, and that portion of the North American station north of New York, with especial reference to the Gulf of St. Lawrence and the coast of Labrador. A mathematical expression giving the component parts of B, viz., P and *c*, without

* *c* is marked + when the north end of the needle is drawn towards the bow, and - when towards the stern. The Flinders bar in the former case must be placed abaft, and in the latter before the compass to counter-act the error. The change of polarity in vertical error which takes place in crossing the magnetic equator is gradual not abrupt.

change of geographical position is known,* but for the reasons given later on,† it is considered an undesirable method. The component parts of B can be obtained, provided B has been ascertained in two different magnetic latitudes, where the dip‡ and H ‡ horizontal force are known: λ is generally known before the ship's departure from England, or must be ascertained according to the directions given above.§ The more widely separated the magnetic latitude (*i.e.*, the dip), the better the results (60° would give good results). The magnets correcting B must remain unchanged in number and position between the observations, or the uncorrected value of the deviation must be known on the east and west points at the two observing stations; and in the mercantile marine, the cargo if magnetic must remain undisturbed.

$$\frac{P}{\lambda} + H \tan. \text{dip} \frac{c}{\lambda} = BH$$

$$\frac{P}{\lambda} + H' \tan. \text{dip}' \frac{c}{\lambda} = B'H'$$

The proper signs prefixed to the dip ||

Taking in the south of England $B = - \cdot 074$

Do. do. Cape $B = - \cdot 136$

c at the first named place would require a correction of $2^\circ \cdot 7$, and at the latter $- 1^\circ \cdot 6$, the amount to be corrected by

Flinders bar for any intermediate position would be $\frac{c}{\lambda} \tan.$

dip; the equivalent length of Flinder's bar for values of c , ¶ are based on a bar 3 inches thick and 9" from the centre of the compass.

Supposing no dominant magnetic force, owing to its proximity, to control the needle, the influence of the general

* Admiralty Manual, page 157.

† See page 55. Heeling error co-efficient.

‡ Given with sufficient accuracy for this purpose in the magnetic charts at the end of this work.

§ Page 52.

|| See Dip, page 16.

¶ See Table III.

magnetism of the ship to the induced magnetism in vertical soft iron, will be $P\ 0.75$, or 0.9 to $c\ 0.25$ or 0.1 .

HEELING ERROR Co-EFFICIENT.—It is desirable before proceeding to describe the heeling co-efficient to reiterate what is practically done or attempted when the heeling magnets are placed in position, and the extent of the correction. To correct a compass, already corrected for quadrantal and semi-circular errors, for heeling error is to make* “the vertical magnetic force at the place of the compass on board to bear the same ratio to the vertical magnetic force on shore, that the horizontal force on board bears to the horizontal force on shore,” the extent and value of the heeling error correction will be best judged by the following opinions. The late Sir G. B. Airy writes: “There appears to be no safe way of determining the amount of the effect of heeling, except by making the ship to heel and observing how much the compass is affected.” Lord Kelvin remarks, “Although the heeling magnet is very useful in bring the heeling error within moderate bounds, the mariner must constantly be on his guard to determine the heeling error by observation, and allow for it when the ship heels over, even though he may know his compass to be correct when the ship is upright.” Captain Mayes (formerly Superintendent of Compasses) in the Journal of the R. U. S. I. states: “The correction of the heeling error is unsatisfactory, and the formula given by Mr. Archibald Smith does not appear to be correct,” and Captain Mayes’ statement was corroborated by a tabulated form† of the compass heeling errors of H.M.S. “*Orlando*” as found by actual experiment and those by calculation. As previously stated, the heeling error‡ is mainly composed of three component parts. (1) Vertical induction in transverse soft iron, represented

* Instructions for the adjustment of Sir William Thomson’s (Lord Kelvin) patent compass.

† Given by Staff Commander (now Captain) Creak, Superintendent of Compasses.

‡ See Heeling error, page 43.

by D and λ . (2) Vertical induction in vertical soft iron, and (3) Vertical permanent magnetism of ship, they are represented by the co-efficient μ (μ). The majority of ships in England are built with their heads to the southward,* and have their standard compasses forward, so that (3) will act downwards, and combine with the soft iron of the ship.

The co-efficient μ is the mean value of the vertical force at the needle to that of the earth, and is calculated from vibrations or by statical measurement. Let Z' be the vertical force of earth and ship on any azimuth θ , and Z the earth's vertical force :

$$\mu \text{ (for any of } \theta) = \frac{Z'}{Z}$$

μ can be attained with the ship's head east or west ; with $\frac{Z'}{Z}$

on any two azimuths 180° apart ; or the mean of $\frac{Z'}{Z}$ on any

number of equidistant azimuths. $\frac{Z'}{Z}$ can be ascertained

(except where the vertical force is small), by landing in a spot free from any local attraction, a freely suspended dipping needle, that is, the instrument must be level ; with the needle's face in the magnetic meridian, the oscillations being at right angles to the meridian, the needle when stationary will be vertical, the horizontal component of the earth's force acting on the needle will be nil. Cause the needle to vibrate ten times through an arc of 15° to 20° from each side of the vertical, note the time, or the mean of times of several sets, calling it t .† Suspend the same needle in the binnacle, note the time of vibrations or the mean of the times,

* Except ships built in private yards, which are located on the north side of rivers.

† By placing a small semi-circular rod of wood, with its flat side downwards, across the top of the binnacle or pedestal, slightly notched in the centre for the chain suspending the instrument, the latter will level itself, and the observations less likely to be disturbed. The resting points of the wood on the binnacle top should be scored for a similar reason.

calling it t' , as the forces will vary inversely as the square of the times of vibration $\frac{t^2}{t'^2} = \frac{Z}{Z'}$; Z being considered as 1.

By statical measurement: HEELING ERROR INSTRUMENT consists of a brass case fitted with a spirit level, one side being of glass and on it is marked a horizontal line; the instrument stands on a flat foot for shore observations, where when used, it should be placed, levelled, on a pedestal not less than three feet from the ground. For ship observations, it is suspended by a chain and hook in the top of the instrument, from a wooden rod laid across the binnacle top in the manner previously described, and the instrument should level itself, but any small alteration of level can be made by a careful movement of the links of the chain. The needle is cylindrical, with pointed ends, the *red* or *north seeking* end is marked by a circle, it is graduated, every fifth division being marked by a dot, the needle is fitted with a sliding aluminium weight or weights; if two be used, they must touch one another and be regarded for purposes of measurement as one; it is mounted on a transverse axis, knife-edged on its under side, and the needle *when not required for observation* is capable of being lifted on brass bearers by a milled screw at the back and bottom of the brass case.

On shore, at a spot free from local attraction, the instrument being levelled, is turned in azimuth until the marked end of the needle is directed to the north. Place the aluminium weight or weights on the uppermost end (unmarked in north magnetic latitudes) until the needle is horizontal, *i.e.*, coinciding with the horizontal line marked on the glass face, the distance (a) is noted from axis of suspension.

Remove the compass to the ship, her head * being east or west magnetic, suspend the instrument to the wooden rod as previously described, with its needle in the same

* For the reasons given on last page of Chapter IV. The ship is supposed to be on even beam—if heeled the ship's head should be north or south magnetic.

horizontal plane to that lately occupied by the needles of the compass card. Turn the instrument in azimuth until the red end of the needle points to magnetic north (nearly), again make the needle horizontal by the sliding weight or weights, and the distance (b) noted from the axis of suspension

$$Z : Z' :: a : b.$$

The method of vibrations is generally adopted to ascertain the values of (2 and 3) the component parts of μ or the amount of heeling error; but for mechanical correction of the heeling error the method by statical measurement is preferable.

μ , as already mentioned, represents the combined effects of (2 and 3) portions of the heeling error, but (1) the portion arising from vertical induction in transverse soft iron is composed of λ and D .

To ascertain the heeling error by vibrations :

$$t' = \frac{t}{\sqrt{\lambda (1 + D)}}.*$$

To ascertain the heeling error by heeling error instrument :

$$b = \lambda a (1 + D).*$$

The heeling error can be corrected at sea by means of the heeling instrument, provided the value of (a) is known at a zero station of high vertical force, such as the British Naval Seaports.

Let a = Number of scale divisions (30) at zero station

b = do. at sea station (required)

Z = Vertical force at zero station (2.36) }
 Z' = do. at sea station (0.50) } From chart

$$\dagger \lambda (1 + D) = 0.908$$

* The quadrantal error is corrected.

† λ is practically constant for navigational purposes, increasing with time but decreasing with heat. D also is practically constant for navigational purposes, but decreases with time.

$$\frac{b}{a} = \frac{Z'}{Z} \times \lambda (1 + D)$$

$$b = \frac{a \times Z' \times \lambda (1 + D)}{Z} = \frac{30 \times 0.50 \times .908}{2.36} = 5.76$$

$a = 5.76$ the number of scale divisions to which the heeling error instrument must be set.

The HEELING Co-EFFICIENT, if known, on the north or south points (points of maximum disturbance) can be found for any other azimuth by multiplying it by the cosine of the azimuth, measured from the points of maximum disturbance.

CHAPTER VI.

WE now proceed to the mechanical correction of the compass ; first the order of the correction, and the reasons for their sequence. It is hardly necessary in the present day to state the reasons for correcting a compass, but the principal ones are equalising the directive force of the needle* for all points of the compass and increasing the steadiness of the compass in a seaway, thus preventing sluggishness on certain ones ; also to cause the angular movement in azimuth, and ship's head to nearly coincide,† a great assistance in fleet tactics, and taking rough bearings at night. A compass should be corrected in the following order—(1) The quadrantal error, (2) the heeling error, and lastly the semi-circular error. A ship is never of such a diverse type from any previous one, but that a rough approximation can be made of her probable quadrantal error (D). The spheres when in place increase the mean directive force of the needle‡ and the heeling error caused by vertical induction in soft iron is largely corrected by the spheres. Heeling error is next corrected, if the ship were not on even beam when correcting (C), a heeling error is introduced which has its maximum on north and south points. The vertical magnets and ends of the fore and aft ones should not be capable of inducing magnetism in Flinders bar (for correction of B (c)).

* The frictional error is, roughly, inversely proportionate to the directive force.

† See table of the large deviations of the "*Trident*" and "*Achilles*" in Admiralty Manual.

‡ A case occurred in which a compass kept at east for an entire revolution in azimuth, until the spheres were placed in position.

If a Flinders bar be used, it should be in place before the vertical magnets are finally adjusted.

To ADJUST.—Place quadrantal spheres in place, according to previous experience ; and as ship proceeds down a river or to a buoy, diminish the semi-circular error if known to exist. On being made fast to a buoy,* swing on the cardinal and inter-cardinal points—ascertain D , to correct a $+ D$ † move spheres closer to compass or use larger spheres, for $- D$ increase the distance or use smaller spheres. If the semi-circular error is found to be large, it is better to adjust a second time before correcting the heeling error, supposing if it were necessary, that it has been done ; the HEELING ERROR is corrected, if by the method of vibrations, in moving the can containing the vertical magnets upwards or downwards by its chain, or by increasing or decreasing the power and number of the magnets until $t' = \frac{t}{\sqrt{\lambda + D}}$, as explained in the previous chapter. BY HEELING ERROR INSTRUMENT with the ship's head east or west,‡ move the can in a similar manner until $b = \lambda a (1 + D)$. §

Should a vessel proceed to sea in north magnetic latitudes, unadjusted for heeling error and the compass in consequence becomes unsteady, the heeling error may be approximately corrected, by placing the ship as nearly as practicable on a north or south course, noting as the ship heels over, whether the north (red) end of the compass is attracted to the windward side of the ship.

* As previously explained, a ship can be steamed round in a circle, according to local circumstances.

† See Table IIA. It is understood that the needles are of such small directive power, that practically they do not produce induced force in the spheres ; with large needles the magnetic power of the spheres would be increased, and the power would vary with the magnetic latitude. Single needle compasses should not be used with spheres, as they cause an octantal error.

‡ For the reasons given in last page of Chapter IV. and footnote page 57.

§ With heeling error instruments supplied to H.M. ships, the value of $(\lambda (1 + D))$ is usually given in MS. for the principal compasses.

If so, the error should be corrected by magnet or magnets red marked ends up; if attracted to leeward side, by magnet or magnets with their blue marked ends up—raising or lowering the can containing the magnets, until a position is reached, where the compass is (roughly) undisturbed by the heeling of the ship.

On crossing the magnetic equator and proceeding to higher magnetic latitudes, it may be necessary to reverse the position of the poles of the magnets in the can.

The can's chain should be carefully secured to prevent it from slipping, to enable a navigating officer to know this has not occurred, a link of the chain is simply marked by twine; between the bottom of the can and the bottom of the well bored for its reception, should be three inches, after the distance by previous experiment has been found; as in many compasses, for instance Lord Kelvin's (which is usually adopted as a standard in H.M. Navy), the method of suspension allows a lateral movement of the compass; so when the ship heels, the centre of the can and the centre of the card are no longer in the same vertical plane and the heeling error is over corrected; it is therefore usual to prevent over-correction by lowering the can one and a half inches* below the amount obtained by instrumental means.

With the number and size of magnets usually employed in heeling error correction, no serious disturbance from this cause need be apprehended until the vertical magnets approach within two feet of the compass cards, but should any doubt exist it is better to practically test it, by inclining the pedestal on a calm, fine day.

To correct the SEMI-CIRCULAR DEVIATION with the ship's head magnetic NORTH; observe the compass-bearing of an object, the magnetic-bearing of which is known.

(a) If the deviation be easterly (+) and the red (north) end

* Should 14-inch magnets be employed, the $1\frac{1}{2}$ inches must be increased to $2\frac{1}{2}$.

of the needle is drawn to starboard, increase in the transverse holes of the pedestal the number of magnets with red ends to starboard, or place them nearer the card, until the magnetic and compass bearings coincide, and there is no deviation.

- (b) If the deviation be westerly (−) and the red (north) end of the needle is drawn to port, the magnets must be placed with their red ends to port or decrease the number of magnets with red ends to starboard or remove them farther away from the card.
- (c) Or with ship's head magnetic SOUTH; if the deviation be westerly (−) and the red (north) end of the needle is drawn to starboard, in the transverse holes of the pedestal, increase the number of magnets with red to starboard or place them nearer the card.
- (d) If the deviation be easterly (+) and the red (north) end is drawn to port, the magnets must be placed with their red ends to port, or decrease the number of magnets with red ends to starboard, or remove them farther away from the card.

If there be no deviation, the co-efficient (C) representing the transverse magnetic force in the ship has been corrected.

- (e) With the ship's head magnetic EAST; if the observed deviation be easterly (+) and the red (north) end of the needle is drawn towards the bow, in the fore and aft holes of the pedestal, increase the number of magnets with red ends forward or decrease their distance from the card—the number of magnets in port and starboard fore and aft holes should be equal in number and strength.
- (f) If the observed deviation be westerly (−) and the red (north) end of the needle is drawn towards the stern, the magnets must be placed with their red ends aft, or the magnets with their red ends forward must be

reduced in number or their distances increased from the card. Or with Ship's head Magnetic West.

- (g) If the observed deviation be westerly (−) and the red (north) end of the needle is drawn towards the bow increase the number of magnets with red ends forward or decrease their distance from the card.
- (h) If the observed deviation be easterly (+) and the red (north) end of the needle is drawn towards the stern, the magnets must be placed with red ends aft, or the magnets with their red ends forward must be reduced in numbers, or their distances increased from the card.

In the above corrections, the principles of like poles repel one another is brought into practice.

If there be no deviation, the co-efficient B, representing the fore and aft magnetic force in the ship, has been corrected. Should it be considered desirable to correct that portion of B (*c*) by the Flinders bar, and the knowledge (special to the ship), with regard to the relative proportions of P and *c* are unknown; correct $\frac{1}{10}$ to $\frac{1}{4}$ of B by Flinders bar, the latter being raised two inches above the level of the compass card.

A, the constant deviation (real), should be small in amount in a properly-placed compass, and remain uncorrected, as it is constant for all courses.

E should be small in amount in a properly-placed compass, and can be corrected, if desirable, as previously stated,* by placing the spheres at such an angle (β) with the athwartship line that $\tan 2 \beta$ will equal $\frac{E}{D}$.

The ship should then be swung, and the deviations tabulated. The maximum deviation in a well-placed compass should be less than 2°.

GENERAL REMARKS AND CAUTIONS.—On a navigating officer joining a ship, he should examine the compass pedestal, that it is properly secured to the deck: (1), the centre

* See page 48.

of the quadrantal spheres and compass needles should be in the same horizontal plane, whether the latter are athwartships, or at angle to the athwartship line; (2),* a vertical plane, passing through the centre of the compass needles, should also pass through the centre of the horizontal plane of the magnets; (3), the spheres and magnets are correct with regard to position, size and number, according to the deviation table (if supplied); (4), the compass bowl moves freely in the gimbals; that the screws securing the glass verge are not worn, as they are made with a special thread, rendering their replacement difficult after leaving a dockyard, as no screw-driver is supplied, the one in the station pointer's box will be found useful; (5), that the lubber's line is in, or parallel to, the fore and aft line; to ascertain this for the Standard, the ship should be on even beam; set the index of the base plate carrying the azimuth mirror at 180° , reflect the centre of any object in the fore and aft line on to the lubber's point, if they agree, the lubber's line is correct, otherwise, turn the pedestal in azimuth until they do agree; if the object be abaft, reverse the bowl in the gimbals, so that the lubber's point will be aft; (6), that one of the faces of the Azimuth mirror when in use is parallel to the face of the glass verge by observing if a bearing remains constant when the object is reflected to the graduation of the card, and when the graduation is reflected to the object; if it differs, the error can be ascertained and allowed for; (7), the key of the door of the pedestal in which the correcting magnets are placed should be in charge of the navigating officer, and any alteration in number, of size or position, should be entered by him in the compass journal; (8), the minimum distance between binnacles should be $4\frac{1}{2}$ feet.

COMPASS CARDS should be stowed with unlike poles together, the numbers on the outside of the compass card-boxes are so marked, that this is carried out by placing the numbers above one another. The cards should be placed in the boxes with the engraved face downwards,* the north

* Refers to Thomson's cards and fittings only.

end of the needle at the (N) end of the box, with the centre of the card over the wooden stud, and the thread attached to north or zero point should be placed between the two metal studs. The pivots and caps should be examined and shipped at convenient opportunity to see the card works freely.*

To ship a Thomson's card, the pivot and cap are taken from the triangular-shaped partition in the compass card-box; the pivot should be forced well home in the holder at the bottom of the bowl; place the centre of the card over the cap—the latter with its rounded end up. Lift the card by the upper portion of the cap, placing it carefully on the pivot, with the card approximately in its correct magnetic position with regard to the ship's head.

The MAGNETS supplied to the service are cylindrical, with painted halves of red and blue (as suggested by the late Sir G. B. Airy), the *red* to mark the end possessing the same description of magnetism as the earth's south polar regions, and *blue* to mark the end possessing the same description of magnetism as the earth's north polar regions. The majority are $\dagger$ $9'' \times \frac{3}{8}''$ and $9'' \times \frac{3}{16}''$ in size, and, except for the purpose of correcting heeling error, are always placed broadside on the compass, $\ddagger$ if the distance and power of a magnet be constant, the force of a magnet end on is double that when broadside on. The spare magnets of the same size should be kept in bundles, with opposite poles together, and placed in the compass locker and not in a drawer of a chart-house, in proximity to a compass.§ The Controller's department state that four feet should be the minimum

* See remarks on manœuvring compass on next page.

$\dagger$ For correcting heeling error fourteen inch magnets are occasionally employed.

$\ddagger$ An exception was the case of the "*Undaunted*" (old), a wooden frigate with iron masts; and exceptions may occur when dealing with vertical iron immediately below the compass.

§ A merchant ship has been known to have had cushions with steel-wire springs on the lockers in a wheel-house, to the confusion of the adjuster, until the source of the error was discovered.

distance between compasses and chronometers ; this should be borne in mind if the latter are removed when preparing for action, and that the intensity of magnetisation of the needles in a liquid compass and a Thomson are widely different.

In practice, when swinging, it is usual to observe alternate points, but including the cardinal and inter-cardinal ones ; and the ship should be kept steady for a few minutes on each point observed, as a ship takes some little time to acquire the magnetism due to that point, and vertical iron is often more sluggish in parting with its induced magnetism than horizontal. The following precautions should be taken in swinging, observing that the ship should always be swung by the standard compass : (1), the magnetic bearing of an additional distant object should be known, in case the original one becomes obscured by masts, funnels, etc. ; (2), in reflecting with the azimuth mirror, avoid unequal pressure on opposite sides of the compass bowl, more especially in a seaway, or blowing hard ; (3), if reflecting a celestial body, the smaller the altitude the better ; the ordinary limit should be 30° , to be increased to 40° under extraordinary circumstances ; (4), if a shadow pen be used, it should be straight and upright.* Finally, the reader is recommended to again peruse the opening paragraphs of Chapter I.

* A manœuvring compass should be kept closely adjusted by the navigating officer, and affords him a ready means of obtaining a practical knowledge of the adjusting. Should a compass become sluggish, due, as far as can be judged, from other than magnetic disturbance, the cap and pivot should be changed ; a trifling imperfection in either of them may be coincident with the moment of the compass. The average period of a Thomson's card varies from thirty seconds for a ten-inch card, to thirteen and a half seconds for a four-inch one.

TABLE I.

For the computation of the Coefficients, B, C, D, E.

PRODUCTS OF ARCS MULTIPLIED BY THE SINES OF THE RHUMBS.

ARCS.	Sin. 11¼°.	Sin. 22½°.	Sin. 33¾°.	Sin. 45°.	Sin. 56¼°.	Sin. 67½°.	Sin. 78¾°.	ARCS.
Nat Sin.	•19509.	•38268.	•55557.	•70710.	•83147.	•92388.	•98078.	
0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
0 10	0 2	0 4	0 6	0 7	0 8	0 9	0 10	0 10
0 20	0 4	0 8	0 11	0 14	0 17	0 18	0 20	0 20
0 30	0 6	0 11	0 17	0 21	0 25	0 28	0 29	0 30
0 40	0 8	0 15	0 22	0 28	0 33	0 37	0 39	0 40
0 50	0 10	0 19	0 28	0 35	0 42	0 46	0 50	0 50
1 0	0 12	0 23	0 33	0 42	0 50	0 55	0 59	1 0
1 10	0 14	0 27	0 39	0 49	0 58	1 5	1 9	1 10
1 20	0 16	0 31	0 44	0 57	1 7	1 14	1 18	1 20
1 30	0 18	0 34	0 50	1 4	1 15	1 23	1 28	1 30
1 40	0 20	0 38	0 56	1 11	1 23	1 32	1 38	1 40
1 50	0 22	0 42	1 1	1 18	1 32	1 42	1 48	1 50
2 0	0 23	0 46	1 7	1 25	1 40	1 51	1 58	2 0
2 10	0 25	0 50	1 12	1 32	1 48	2 0	2 8	2 10
2 20	0 27	0 54	1 18	1 39	1 56	2 9	2 17	2 20
2 30	0 29	0 57	1 23	1 46	2 5	2 19	2 27	2 30
2 40	0 31	1 1	1 29	1 53	2 13	2 28	2 37	2 40
2 50	0 33	1 5	1 34	2 0	2 21	2 37	2 47	2 50
3 0	0 35	1 9	1 40	2 7	2 30	2 46	2 57	3 0
3 10	0 37	1 13	1 46	2 14	2 38	2 56	3 6	3 10
3 20	0 39	1 17	1 51	2 21	2 46	3 5	3 16	3 20
3 30	0 41	1 20	1 57	2 29	2 55	3 14	3 26	3 30
3 40	0 43	1 24	2 2	2 36	3 3	3 23	3 36	3 40
3 50	0 45	1 28	2 8	2 43	3 11	3 33	3 46	3 50
4 0	0 47	1 32	2 13	2 50	3 20	3 42	3 55	4 0
4 10	0 49	1 36	2 19	2 57	3 28	3 51	4 5	4 10
4 20	0 51	1 40	2 24	3 4	3 36	4 0	4 15	4 20
4 30	0 53	1 43	2 30	3 11	3 45	4 10	4 25	4 30
4 40	0 55	1 47	2 36	3 18	3 53	4 19	4 35	4 40
4 50	0 57	1 51	2 41	3 25	4 1	4 28	4 44	4 50
5 0	0 59	1 55	2 47	3 32	4 9	4 37	4 54	5 0
5 10	1 1	1 59	2 52	3 39	4 18	4 46	5 4	5 10
5 20	1 2	2 3	2 58	3 46	4 26	4 56	5 14	5 20
5 30	1 4	2 6	3 3	3 53	4 34	5 5	5 24	5 30
5 40	1 6	2 10	3 9	4 0	4 43	5 14	5 34	5 40
5 50	1 8	2 14	3 14	4 8	4 51	5 23	5 43	5 50
6 0	1 10	2 18	3 20	4 15	4 59	5 33	5 53	6 0

Tables II., IIa., and III., with the Magnetic Charts, are taken from Admiralty Manual (edition 1893).

TABLE II.

QUADRANTAL DEVIATION. CORRECTION BY SPHERES.

*Distances of Spheres to correct given values of Coefficient D.
10" Thomson Binnacles, brass brackets.*

Position of Spheres.	Amount of D that will be corrected with different sized Spheres.					
	5" Spheres.	8" Spheres.	7" Spheres.	8½" Spheres.	10" Spheres.	12" Spheres.
Close up* inches.	2 20	3 0	4 39	6 20	8 0	10·36
Set out ·1	2 17	2 55	4 32	6 10	7 46	
·2	2 13	2 50	4 25	6 0	7 33	
·3	2 10	2 45	4 20	5 50	7 20	
·4	2 6	2 41	4 15	5 42	7 10	
·5	2 2	2 38	4 10	5 35	7 0	
·6	2 0	2 34	4 3	5 28	6 49	
·7	1 57	2 30	3 57	5 20	at extreme.	
·8	1 53	2 26	3 51	5 12		
·9	1 50	2 23	3 45	5 7		
1·0	1 48	2 19	3 40	5 0		
1·1	1 45	2 16	3 34	4 53		
1·2	1 42	2 12	3 29	4 47		
1·5	1 36	2 3	3 13	at extreme.		
2·0	1 26	1 49	3 3	at extreme.		
2·5	1 15	1 36	at extreme.			
3·0	1 4	at extreme.				
3·5	0 56					
	at extreme.					

* Distance of centre of Compass to the nearest point of Spheres in the position "close up" = 8·5 inches.

TABLE IIa.

QUADRANTAL DEVIATION. CORRECTION BY SPHERES.

*Distances of Spheres to correct given values of Coefficient D.
6" Compass in Thomson Canning Tower Suspension, brass brackets.*

Position of Spheres.	Amount of D that will be corrected with different sized Spheres.				
	5" Spheres.	6" Spheres.	7" Spheres.	8½" Spheres.	10" Spheres.
Close up* inches.	⁰ / ₅ 0	⁰ / ₇ 35	⁰ / ₁₀ 50	⁰ / ₁₃ 50	⁰ / ₁₆ 15
Set out .1	4 50	7 18	10 26	13 20	
.2	4 40	7 0	10 5	12 53	
.3	4 30	6 44	9 48	12 30	
.4	4 21	6 30	9 30	12 10	
.5	4 12	6 18	9 10	11 48	
.6	4 4	6 05	8 53	11 32	
.7	3 56	5 55	8 38	at extreme.	
.8	3 48	5 45	8 22		
.9	3 40	5 35	8 8		
1.0	3 32	5 25	7 52		
1.1	3 27	5 16	7 38		
1.2	3 21	5 9	7 23		
1.5	3 2	4 48	7 15		
2.0	2 34	4 12	at extreme.		
2.4	2 12	at extreme.			
	at extreme.				

* Distance of centre of Compass to the nearest point of Spheres in the position "close up" = 5.1 inches.

NOTE.—This Table will serve for 6" Binnacles if 30' be added to the values here recorded.

TABLE III.

SEMICIRCULAR DEVIATION.

Correction of c, the changing part of coefficient B, by Flinders bar.

Table of Equivalent lengths of Flinders Bar, to correct values of C.		
Value of c.	Amount to be corrected in south of England where tan. dip = 2°33.	Length of bar in inches.
·01	1 20	6·5
·02	2 40	8·2
·03	4 00	9·5
·04	5 20	10·8
·05	6 40	12·2
·06	8 00	13·2
·07	9 25	14·2
·08	10 45	15·2
·09	12 06	16·3
·10	13 30	17·4
·11	14 50	18·4
·12	16 15	19·5
·13	17 35	20·6
·14	19 00	21·9
·15	20 30	23·1
·16	21 55	24·4

NOTE.—These values have been computed for an average Flinders bar of malleable iron, 3 inches in diameter, and made up of different lengths. If c be known, or can be assumed, the equivalent length of bar can be at once placed in position.

When c has the sign +, on the after side of Binnacle.

When c has the sign −, on the fore side of Binnacle.

These values of c and equivalent lengths of bar are chiefly intended for a first adjustment.

λ , if unknown, may be assumed.

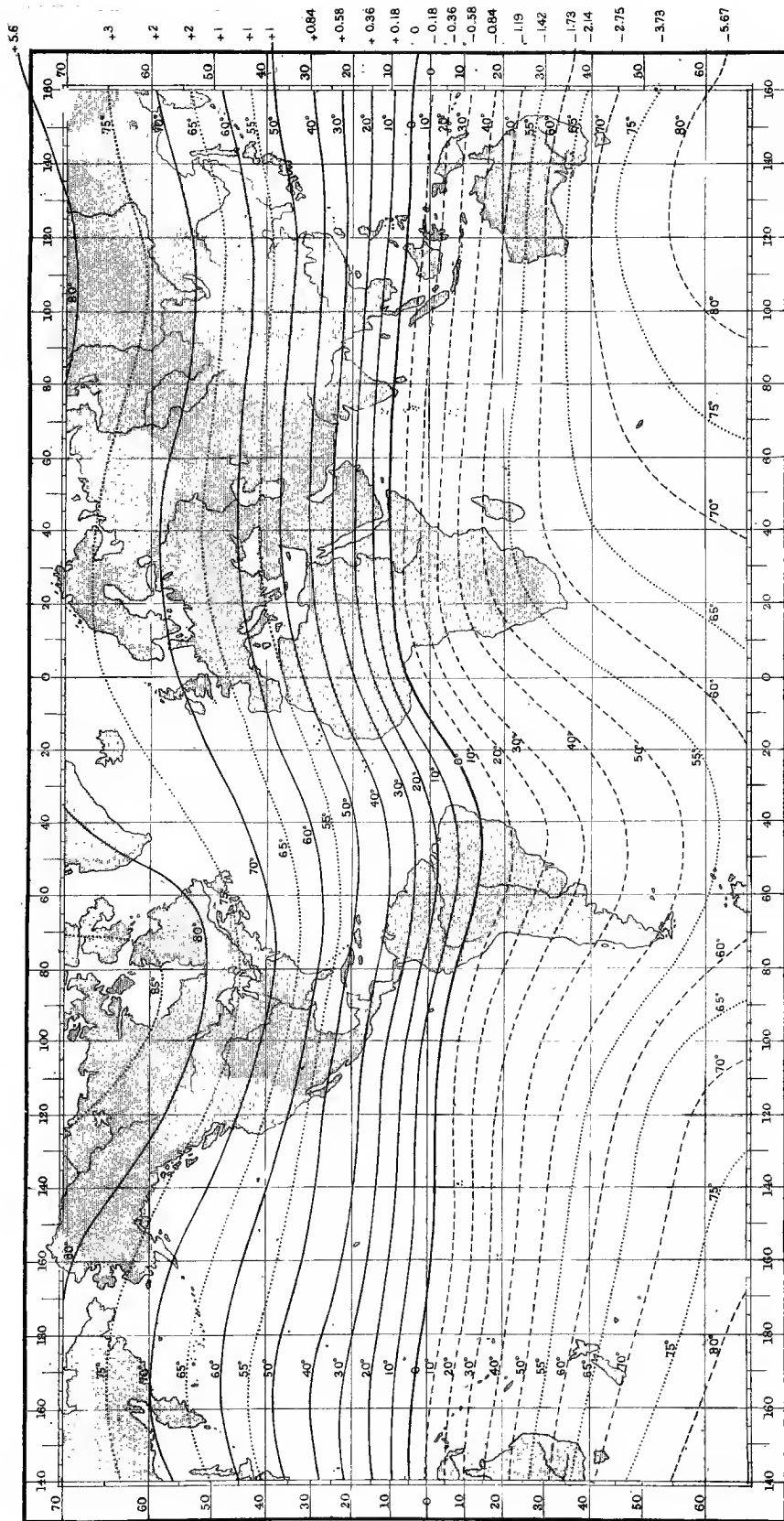
* For an iron or steel ship 0°90.

* With armoured decks in above 0°85.

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED
STAMFORD STREET AND CHARING CROSS.

Lines of Equal Magnetic DIP. 1895

Nat.
D

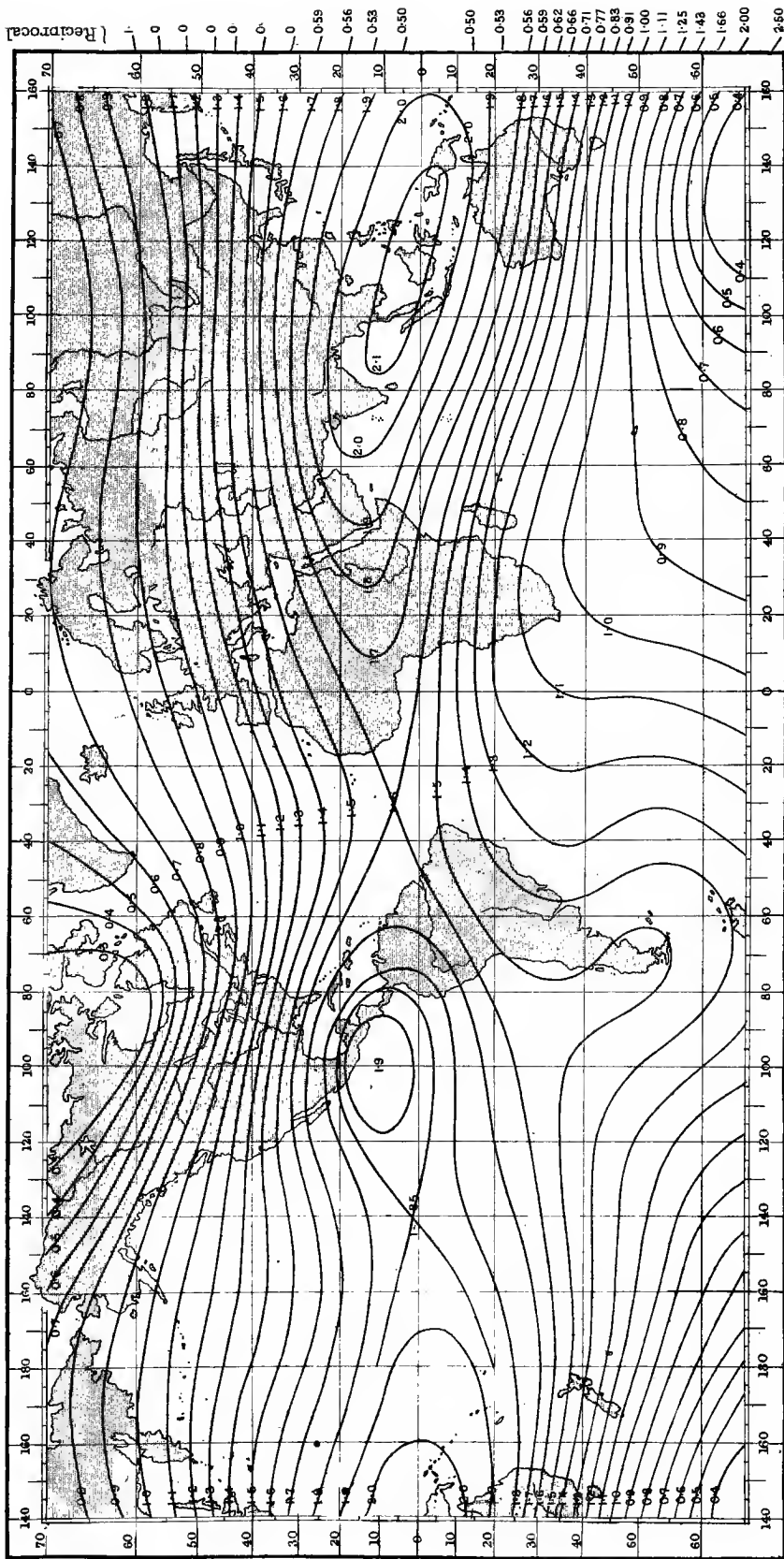


Engraved by Malby & Sons.

Nº 2.

Lines of Equal Horizontal Force. 1895.

[Horizontal Force at Greenwich-1.0-H]

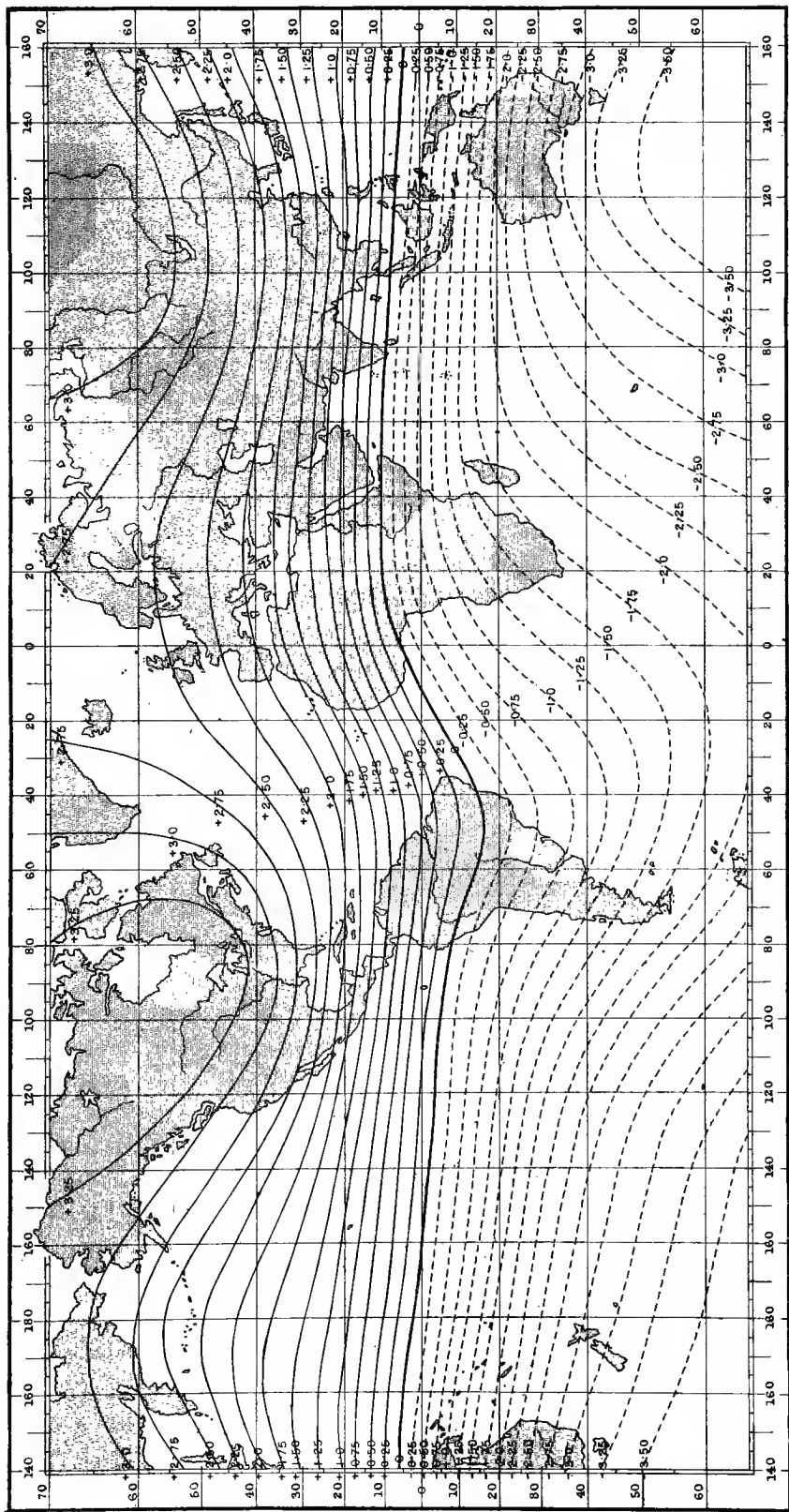


Engraved by Mally & Sons.

No. 3

Lines of Equal Vertical Force. 1895.

[Vertical Force = $Z - H \tan \text{Dip}$. (H at Greenwich = 10)]



Engraved by Mally & Sons

